Columbia River
Keenleyside Powerplant Project

Preliminary Design Study
Phase 1

B.C.Hydro
Hydroelectric Generation Projects Division

Report No. H1613

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COLUMBIA RIVER
KEENLEYSIDE POWERPLANT PROJECT

PRELIMINARY DESIGN STUDY
PHASE 1

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PRELIMINARY DESIGN STUDY

PHASE 1

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SYNOPSIS

SYNOPSIS

The Hugh Keenleyside Dam, completed in late 1968, is located on the Columbia River, approximately 7 km upstream of the City of Castlegar. It was constructed, under the terms of the Columbia River Treaty, to provide storage (Arrow Lakes Reservoir) for downstream flood control, to increase power generation in the United States, and to increase generation in Canada when power facilities were added. The project presently includes no generating facilities.

Studies of adding generating facilities at Keenleyside Dam were begun in late 1978 in parallel with similar studies already under way for the Murphy Creek Project, some 34 km downstream. Studies of both projects were conducted concurrently because the reservoir level selected for the Murphy Creek Project would directly affect the tailwater level and generating capability at Keenleyside. For a combined Keenleyside-Murphy Project, the recommended nominal reservoir level for the Murphy Creek Project is El. 424.0. The two projects would develop a combined head of about 31 m with approximately half at each site.

Because of the considerable drawdown of the Arrow Lakes Reservoir with current operation under the Treaty, studies were made of several alternative operating regimes representative of both present conditions and long-term conditions when expiry or modification of the Treaty would permit reduced drawdown, increased generation at both Keenleyside and Murphy Creek and reduced environmental impacts. An operating regime that would reflect these benefits has been adopted for project design.

The powerplant would be located on the left bank adjoining the end of the existing concrete dam. Field investigations have shown that the proposed powerplant structures would be founded on competent bedrock and that sufficient construction materials are available locally.

The proposed 210 MW powerplant would contain three 70 MW generating units having vertical shaft Kaplan turbines. The project arrangement would include a short intake approach channel immediately upstream of the dam and a short tailrace channel leading back to the river in the vicinity of the existing discharge structures. The powerplant would be constructed within earth and rockfill cofferdams required both upstream and downstream of the existing dam. Operation of the reservoir and discharge facilities would be unaffected during the 6 1/2-year construction period.

Based on B.C. Hydro's 1983 Electric System Plan, the first unit would be in service in August 1992 with Units 2 and 3 following in December 1992 and August 1993.

The estimated total construction cost of the Keenleyside Powerplant Project, excluding inflation, interest during construction and corporate overhead would be $314 million (October 1982 price levels).

Based on the long-term operating regime used for project design, average annual generation from the 210 MW powerplant would be 880 GW.h.

SECTION 1.0 - INTRODUCTION

1.1 BACKGROUND

Under the terms of the Columbia River Treaty, the Hugh Keenleyside Dam was constructed to provide storage for downstream flood control, to increase power generation in the United States and to increase generation in Canada when power facilities were added. The dam, an earthfill and concrete structure on the Columbia River 7 km upstream of Castlegar (see Figs. 1-1 and 1-2), was completed in late 1968. The dam controls runoff from a 36 500 km^2 drainage area and impounds a reservoir (Arrow Lakes Reservoir) having a live storage of $8.8 \times 10^9 m^3$ extending 233 km north to Revelstoke.

Generating facilities at Keenleyside Dam were investigated during the design of the dam,[1] but it was decided not to include any provision for them in the initial construction. Feasibility studies of the downstream Murphy Creek Project[2] were completed in 1981 and, because of the considerable interdependence of Keenleyside and Murphy, a prefeasibility level study for Keenleyside[3] was undertaken to permit a combined optimization of both projects. Keenleyside generation was studied in combination with a range of reservoir levels for the Murphy Creek Project. In addition to a "no Murphy" case, alternative Murphy reservoir levels of Els. 424, 427 and 430 were investigated. These levels are respectively 4, 7 and 10 m above the existing tailwater level at Keenleyside under average flow conditions and, therefore, would significantly affect the potential generating capability at Keenleyside. Based on subsequent optimization studies,[4] a Murphy Creek reservoir level of El. 424 was selected as the basis for further studies.[5,6]

Phase 1 Preliminary Design Studies for the Keenleyside Powerplant Project were begun in late 1981 and are documented in this report. Similar studies[7] for the Murphy Creek Project have also been completed.

1.2 ASSIGNMENT

Under Engineering Assignment No. 481-088 dated 18 September 1981, the Hydroelectric Generation Projects Division of B.C. Hydro was authorized to conduct Phase 1 Preliminary Design Studies for generating facilities at the Hugh Keenleyside Dam.

Principal focus was to be on a case having a nominal reservoir level of El. 424 at the downstream Murphy Creek Project with supplementary investigations of alternative Murphy reservoir levels of Els. 421 and 427. For the case with Murphy 424, studies at Keenleyside were to be conducted considering both vertical and horizontal shaft generating units.

To facilitate preparation of an application for an Energy Project Certificate (EPC) and to assist concurrent environmental studies, an Engineering Description[6] of the Keenleyside Powerplant Project was also to be prepared.

1.3 SCOPE OF WORK

In general, the Phase 1 studies included field investigations, office studies and hydraulic model studies sufficient to reach all major decisions regarding the following project features:

1. Arrangement of structures.

2. Type and number of units.

3. Optimum turbine and generator capacity.

4. Optimum reservoir level for the Murphy Creek Project.

The principal studies and investigations were as follows:

1. Derivation of the magnitude of the Probable Maximum Flood (PMF) to ensure sufficient discharge capacity with increased tailwater levels (due to Murphy Creek Project).

2. Derivation of the magnitude of the Diversion Design Flood (DDF) to establish the crest level of the downstream cofferdam necessary for powerplant construction.

3. Foundation investigations for the powerplant site.

4. Construction material investigations for concrete aggregate and glacial till (impervious fill).

5. Design, layouts and cost estimates for alternative unit types including vertical shaft Kaplan turbines and horizontal shaft bulb or straight flow units. All of the unit type comparisons were made for the case having a Murphy reservoir level of El. 424.

6. Design, layouts and cost estimates for three alternative reservoir levels for the downstream Murphy Creek Project; Els. 421, 424 and 427. For all three levels, vertical shaft Kaplan turbines were assumed. The cost estimates were prepared for use in the benefit/cost study[8] to review the selection of El. 424 as the nominal reservoir level for the Murphy Creek Project.

7. Computer simulated power studies for the three alternative Murphy reservoir levels and for two different operating regimes for the Arrow Lakes Reservoir, Regime 1 generally representing existing

operation and Regime 2 representing future operation with reduced reservoir drawdown and significantly increased generation potential.

8. Optimization studies for the selection of installed generating capacity.

9. Hydraulic model studies to refine the arrangement of the principal project components.

10. Preparation of detailed construction schedules for the principal alternatives.

11. Preparation of an Engineering Description.

12. Preparation of this report on the Phase 1 Preliminary Design Study.

SECTION 2.0 - PROJECT AREA

2.1 AREA DESCRIPTION, LOCATION AND ACCESS

The Columbia River drainage basin (Fig. 1-1) is located in southeastern British Columbia to the west of the Rocky Mountains, and is some 500 km inland from the Coast Mountains. From its source, Columbia Lake, the Columbia River flows about 330 km northwest along the Rocky Mountain Trench and through Kinbasket Lake Reservoir to Big Bend where the river makes an abrupt turn and passes the Mica Project. It then flows almost due south for about 450 km, through the Selkirk Trench, past the Revelstoke (under construction) and Hugh Keenleyside dams, to reach the international boundary. From the boundary the river continues through the United States to the Pacific Ocean.

The Columbia River drainage area above the Hugh Keenleyside Dam is characterized by wide glaciated valleys and high mountain chains which cross the region along a northwest-southeast axis. The drainage basin to the east is bounded by the Rocky Mountains. The western edge of the drainage basin is formed by the Monashee Mountains in the south and by the Columbia Mountains in the northwest. Running parallel between the Monashee Mountains and the Rocky Mountains are the Selkirk Mountains which separate the Arrow Lakes valley from the Kootenay Lake valley, and the Purcell Mountains which separate the Kootenay Lake valley from the Rocky Mountain Trench. The mountains tend to be lower in the south, but the ranges all contain peaks that rise to 3000 m, and each mountain chain forms a significant elevation barrier to the prevailing weather systems coming from the Pacific Ocean in the west.

Most of the Columbia River basin remains in its virgin forested state. Dense forest vegetation thins above 1500 m and tree lines lie generally in the 1800 to 2100 m elevation range. Past glaciation of the whole region has left many valley floors filled with large natural lakes, and over the last two decades some of the valleys have become occupied by major hydroelectric and flood control reservoirs. Kinbasket Lake Reservoir, behind Mica Dam, forms a large lake in the Rocky Mountain Trench extending 200 km from Valemount in the northwest corner of the basin to Donald. The Revelstoke Project, presently under construction, will control water levels in the 120 km section of the Columbia River downstream of Mica Dam. The Arrow Lakes Reservoir forms a 233 km long lake from the City of Revelstoke to near the City of Castlegar.

The Hugh Keenleyside damsite is located within an east-west reach of the Columbia River, some 7 km upstream of Castlegar (see Fig. 1-2). From Castlegar, the damsite can be reached by paved roads on either side of the Columbia River. The Canadian Pacific Railway also passes the damsite on the south side of the river.

2.2 DEVELOPMENT OF THE COLUMBIA RIVER

The Columbia River flows a distance of 760 km from its source in Columbia Lake to the Canada-U.S.A. border near Trail; in this course, it falls about 410 m from El. 810 to El. 400 (see Fig. 2-1).

Currently, with the Mica, Revelstoke and Hugh Keenleyside dams, some 510 km of the Columbia River are or soon will be developed, utilizing a combined drop in the river of approximately 334 m.

Mica Dam became operational in 1973 and provides 14.8 x $10^9 m^3$ of live storage, of which 8.6 x $10^9 m^3$ are committed to operation under the Columbia River Treaty. Power facilities at Mica develop a head of about 170 m and have an ultimate rated capacity of 2610 MW. The regulated discharge from Mica has made possible a run-of-the-river plant at Revelstoke with a head of about 125 m. Construction of the 2700 MW (ultimate) Revelstoke Project began in 1976. The Arrow Lakes Reservoir, formed by the Hugh Keenleyside Dam, became operational in 1968.

Based on B.C. Hydro's 1983 Electric System Plan, the first unit of the proposed Keenleyside Powerplant is scheduled to be in service in August 1992. The first unit of the proposed Murphy Creek Project, 34 km downstream of Keenleyside, is scheduled to be in service in July 1993. The Keenleyside Powerplant and Murphy Creek projects would utilize the 31 m of available head between Revelstoke and the Murphy Creek damsite.

2.3 REGIONAL GEOLOGY

(a) Regional Setting

The Hugh Keenleyside Dam is located in a section of the Columbia River known as Castlegar Narrows. This section of the river occupies an east-west trending valley which connects the north-south trench of the Arrow Lakes Reservoir with the north-south trench extending south from Slocan Lake (Fig. 1-1).

The Columbia valley, at the site, is the result of both fluvial and glacial erosion. In the Castlegar Narrows section, glacial erosion of bedrock was less intense than in the valley farther north. The valley was not widened as much and bedrock ridges, such as the one on which the concrete structures are founded, were only partially eroded and rounded off.

In the Hugh Keenleyside Dam area unconsolidated deposits of both fluvial and glacial origin occur in the valley and on the slopes.

The bedrock formations found in the project area are shown on Fig. 2-2.

(b) Bedrock Geology

The area is underlain mostly by plutonic rocks of the Nelson batholith, which consist principally of granite and granodiorite. The age of these rocks is Upper Jurassic to Lower Cretaceous.

The remaining bedrock in the project area consists mostly of sedimentary and igneous rocks, both intrusive and extrusive, generally metamorphosed and ranging in age from Lower Paleozoic to Cenozoic (Tertiary).

The structure of the area is closely related to and influenced by the emplacement of the Nelson batholith. However, most of the major structures were formed before the emplacement of the Nelson batholith and its satellites. The detailed structure of the area is complex with contacts between formations frequently gradational and poorly defined. The rocks are highly metamorphosed, strongly foliated and jointed. The strike of the gneissosity is somewhat erratic although regionally it conforms to the boundaries of the Nelson batholith. Many of the Nelson plutonic rocks also exhibit a gneissic foliation, though locally the rocks vary from massive to moderately well foliated.

There are no known major faults near the site. The regional fault system closest to the project site is the Fraser-Pasayten Fault, about 200 km to the southwest. The thrust faults of the Rocky Mountains are about 150 to 300 km to the northeast. Most of the other known faults in the region occur to the south and southeast, outside the Nelson batholith in older sedimentary and volcanic rocks.

(c) Surficial Geology

The most prominent unconsolidated deposits in the Columbia valley are remnants of terraces containing fluvial and glacio-fluvial deposits consisting mainly of sand, gravel, cobbles and boulders and minor amounts of silt. Glaciers retreating from the Columbia River valley provided large volumes of glacial outwash that were deposited in the river bottoms. Deposition in the Columbia River valley was supplemented by sands and gravels deposited at the mouths of tributaries which may have carried substantial flows of meltwater. In post-glacial time the Columbia and Kootenay rivers eroded and reworked the mass of stratified drift to form a series of river terraces. Hence, the terraces on both sides of the river are remnants of a continuous fill of sediment through which the Columbia River has cut down about 150 m to its present level.

The terraces occur at various levels in different sections of the valley; near the Hugh Keenleyside damsite, terraces at about El. 425 and El. 520 are common. The lower terrace is generally well preserved along one or both sides of the river and actually ranges from about El. 420 to El. 460. Remnants of the upper terrace actually range from about El. 510 to El. 580 and occur only where there are bedrock ledges to support them. Steep valley walls comprise mostly exposed bedrock.

The upper terrace materials consist mostly of sand and silty sand deposited as outwash along the margins of retreating valley glaciers. These fine grained materials are well exposed in road cuts along the lower section of the Balfour till pit road.

The lower terrace consists of outwash and floodplain materials deposited in the valley bottom as the glacier retreated. These deposits tend to be coarse and bouldery, but also include fine materials derived from erosion of the upper terraces. Therefore, a wide size range of materials is common and horizons in these deposits are often discontinuous.

Based on earlier exploratory drilling at the site, these valley bottom deposits are known to be at least locally in excess of 150 m deep. One bore hole, No. 146, was drilled to a depth of 154 m (El. 276.9) without reaching bedrock.

The upper valley walls above the upper terrace are locally mantled by a dense glacial till. This till tends to infill depressions between bedrock ridges and is therefore quite discontinuous and variable in depth.

2.4 CLIMATE

Precipitation in the Columbia River basin develops mainly from the flow of moist low pressure weather systems which move eastward through the region from the Pacific Ocean. The average annual precipitation in the basin (approximately 1000 mm) is more moderate than in Coast Range basins which are exposed to the full impact of Pacific weather systems. As the basin topography exerts a strong influence on local climate, marked constrasts are observed between precipitation amounts at different locations in the basin. For example, the average annual precipitation is 370 mm at Canal Flats in the Rocky Mountain Trench and is 2170 mm at Mount Fidelity, a high-elevation station.

The summer climate is usually very hot and dry, with average daily temperature maxima and minima of approximately 25°C and 10°C, respectively. In the winter, these values are 0°C and -5°C, respectively. The two large reservoirs in the basin, Kinbasket Lake and Arrow Lakes Reservoir, have a slight moderating effect on temperatures at locations adjacent to the reservoirs. In general, temperatures throughout the basin tend to be more uniform than precipitation.

SECTION 3.0 - PROJECT DESCRIPTION

3.1 EXISTING FACILITIES

The Hugh Keenleyside Dam was constructed at a site where granodiorite bedrock occurs at a fairly shallow depth on the left (north) abutment but dips steeply southward under the original riverbed. The dam comprises a number of concrete structures (some 360 m long) founded on bedrock on the left abutment and a 450 m long earthfill dam founded on silts, sands and gravels in the riverbed and on the right abutment. The general arrangement of the existing facilities is shown on Fig. 3-1. An upstream elevation of the dam and typical sections through the principal structures are shown on Figs. 3-2 and 3-3. To control seepage under the earthfill dam and around the north concrete bulkhead, an impervious till blanket was placed extending some 680 m upstream of the dam.

The concrete structures comprise, from the left abutment, the 100 m long north bulkhead; low level ports Nos. 1 to 4 (four 6.1 m wide x 7.3 m high gated outlets with sill El. 411.5); the sluiceway containing four 15.2 m wide x 16.8 m high vertical lift gates with a crest level of El. 424.9; low level ports Nos. 5 to 8 (similar to Nos. 1 to 4); the navigation lock (15.2 m wide and 88 m between gates); and the south bulkhead section connecting with the earthfill dam.

The earthfill dam has sand and gravel shells and a sloping upstream impervious till core connected to the blanket (Fig. 3-3). The maximum height of the dam, above the original riverbed, is approximately 52 m.

The crest level of the concrete structures is El. 443.8 rising to El. 444.7 at the left abutment and at the earthfill dam.

The normal maximum reservoir level is El. 440.1. However, the dam was designed for temporary surcharge to El. 441.7. To improve flow regulation for downstream U.S.A. powerplants, and with the permission of the Comptroller of Water Rights, the reservoir has been temporarily surcharged to El. 440.7 in seven of the last 12 years. Between El. 440.1 and the normal minimum reservoir level of El. 419.6, the reservoir contains a useable storage of 8.8 x $10^9 m^3$. The 0.6 m surcharge contains an additional 0.3 x $10^9 m^3$. Reservoir area and volume curves are shown on Fig. 3-4.

Tailwater rating curves at the navigation lock for natural conditions (without the Murphy Creek Project) are shown on Fig. 3-5. As indicated, the tailwater levels are dependent not only on the flow in the Columbia River, but also on the flow in the Kootenay River which joins the Columbia River 10.5 km downstream.

Because of the flow constriction between the downstream end of the rockfill groin and the north riverbank (see Fig. 3-1), tailwater levels adjacent to the sluiceway and low level ports are somewhat higher than levels measured at the navigation lock gauge. Limited testing on the hydraulic model (see Section 7.0) indicates that the difference in tailwater levels ranges from zero (no discharge from Keenleyside) to about 0.7 m at flood discharges at or above 4300 m^3/s (with concurrent Kootenay River discharges exceeding 2000 m^3/s). For flows greater than these the tailwater level difference remains generally constant due to increasing discharge over the rockfill groin.

Discharge rating curves for the sluiceway and low level ports are shown on Fig. 3-6. Under existing conditions with no Murphy Creek Project, the discharge capacity of the low level ports is dependent on the flow in the Kootenay River because, as described above, the Kootenay flow affects the tailwater levels at Keenleyside. However, as the sluiceway crest level is at El. 424.9 - above normal tailwater levels - the discharge capacity of the four sluices is not significantly affected by downstream flow conditions or tailwater levels.

To permit use of the discharge rating curves with or without the Murphy Creek Project, the curves have been plotted as a function of tailwater level rather than Kootenay River flow. For natural conditions, the discharge capacity can be determined by first finding the tailwater level from Fig. 3-5. For defined tailwater levels such as the El. 424.0 limit established for the Murphy Creek Project, the discharge capacities may be obtained directly from Fig. 3-6. It should be noted that, when determining discharge capacities from Fig. 3-6, the tailwater level at the navigation lock (not the level above the rockfill groin) is to be used.

3.2 PROPOSED POWERPLANT

The proposed powerplant would be located on the left (north) bank, between the existing discharge facilities and the Robson-Broadwater Highway, as bedrock at an elevation suitable for the powerplant foundation is present only on the north abutment.

During the prefeasibility and preliminary design studies three basic arrangements for the powerplant were considered. One would involve use of four of the eight low level ports as intakes for two generating units. The second arrangement would involve a 900 m long canal skirting the impervious blanket as suggested during earlier studies in 1962. These two alternatives are described in detail in Section 6.0. The third and selected alternative, as described in Section 8.0, would comprise a powerhouse adjacent to the end of the existing north bulkhead section with a short intake approach channel connected to the reservoir immediately upstream of the dam. The proposed powerplant would contain three 70 MW generating units driven by vertical shaft Kaplan turbines as shown on Fig. 6-3. Alternative unit types considered are described in Section 6.2.

SECTION 4.0 - HYDROLOGIC AND POWER STUDIES

4.1 GENERAL

Hydrologic studies for the Keenleyside Powerplant Project comprised mainly a review of the probable maximum flood, an assessment of the effects of the Murphy Creek reservoir on the existing discharge facilities at Keenleyside and a review of flood frequencies to establish cofferdam crest levels during construction. Estimates[9] of the Probable Maximum Flood and the Diversion Design Flood were derived largely on the basis of the comprehensive hydrologic studies[10,11] conducted for the Murphy Creek Project.

The basic data on flows, reservoir levels, tailwater levels and heads as used in the power studies were provided by the System Engineering Division. Studies were performed on a computer model developed in 1979 specifically to simulate operation of the Keenleyside Powerplant, the Murphy Creek Project and Cominco's Brilliant plant on the Kootenay River. The studies were carried out for several different operating regimes for the Columbia River storage, the two most significant being as follows:

Regime 1

This operating regime is based on the Columbia River Treaty - Assured Operating Plan (AOP) developed for the operating year 1985/86. It assumes that development of the Keenleyside-Murphy Project would not significantly alter the existing operation of the Columbia River System and is considered to be fairly representative of the first few years of operation of the Keenleyside Powerplant and Murphy Creek Project.

Regime 2

With an expected life of at least 70 years, the Keenleyside Powerplant and Murphy Creek Project would be operated well beyond year 2024, the earliest possible expiration date for the Columbia River Treaty. Regime 2 was developed to better reflect more flexible, future operating conditions that would maximize generation at Keenleyside and Murphy and would mitigate some of the environmental impacts caused by reservoir drawdown.

4.2 PROBABLE MAXIMUM FLOOD

The Probable Maximum Flood (PMF) for Keenleyside Dam was estimated using computer modelling (UBC Watershed and Flow models) of the basin. Model calibration was based on hydrometeorological data covering a continuous period (1970-77) that included some of the largest floods on record. The calibrated models then provided the basis for extrapolation of the basin runoff response characteristics from situations experienced in the period of record to those which might prevail under extreme flood conditions.

Runoff conditions resulting in the PMF peak flow would be produced by the joint occurrence of an extremely large snowpack (1000-year return period) in early July and an extreme temperature sequence (1000-year return period) lasting over a period of approximately 3 weeks. This weather sequence would be followed by the Probable Maximum Rain event at a time when Arrow Lakes Reservoir and upstream reservoir flood control capability would not be available to attenuate this peak runoff.

The PMF for the Keenleyside Dam was calculated to be 10 300 m^3/s; concurrent Kootenay River discharges are expected to be no greater than 2800 m^3/s. With the Arrow Lakes Reservoir at its normal maximum level, El. 440.1, the discharge facilities at the dam have enough capacity to pass the PMF discharge. Construction of the Murphy Creek Project (maximum normal reservoir level of 424 m) would not reduce the discharge capacity at Keenleyside Dam below that which would be required to pass the PMF discharge. A graphical representation of the PMF event is given in Fig. 4-1.

4.3 DIVERSION DESIGN FLOOD

The Diversion Design Flood was tentatively estimated as the peak 24-hour discharge from the Keenleyside Project that would occur, on average, once every 30 years. This flow was used to select the crest level for the downstream cofferdam required for powerhouse construction. A risk analysis during the next phase of studies will determine whether the 30-year frequency results in the most economic design or whether a different frequency should be used.

For the current study, it was assumed that Mica and Arrow Lakes reservoir regulation would occur in the following manner:

1. Reservoir storage would be drawn down by 1 April of each year by an amount calculated to have a 95 percent probability of refill by 31 July (requirements of the Columbia River Treaty).

2. Project discharges after 1 April would be kept at their minimum values until refill was completed. This schedule of project discharges results in the greatest flood potential at Keenleyside Dam but is considered appropriate under conditions of major basin wide (Canada and U.S.A.) flood risk. After the time of refill, all reservoir inflows would be passed.

Routing calculations were then made to find the peak flow that would have occurred in each of the years of record, 1913-77, under the above assumptions. The 30-year flood was determined from a frequency analysis (log-normal distribution) of these hypothetical peak annual flows. In this way, the Diversion Design Flood was calculated to be 4290 m³/s. The concurrent Kootenay River discharge is expected to be no greater than 2020 m³/s.

4.4 POWER STUDIES - REGIME 1

The system power studies were performed using a monthly time interval in the simulations. Regulated reservoir levels and releases for both the Columbia and Kootenay rivers were based on a 35-year period of historical stream flows from August 1940 to July 1975 with regulation in accordance with the 1985/86 Assured Operating Plan.

A summary of monthly mean reservoir levels, tailwater levels and discharges from Keenleyside based on Regime 1 is shown on Fig. 4-2. The 35-year maximum, mean and minimum values are given for each month. As illustrated on the plot of tailwater levels, the Murphy Creek reservoir would have to be drawn down below the nominal level of El. 424 generally from mid-January to mid-June to permit the regulated releases from Keenleyside.

The 35-year mean monthly gross heads at Keenleyside for the Murphy 424 case shown would range from 0.6 m in March to 15.9 m (16.5 m with the 0.6 m surcharge) in August. Although not included in the simulations, it has been assumed that the temporary reservoir surcharge in high runoff years would continue in the future on the same basis as in recent years. The mean gross head from February to May, inclusive, would be only 1.3 m based on Regime 1. Assuming a minimum gross head of 7.0 m for powerplant operation, the Keenleyside Powerplant would be shut down for 4 to 5 months per year.

The 35-year mean monthly total releases from Keenleyside would range from about 600 m³/s to 2400 m³/s with the highest releases generally in

January and February during reservoir drawdown (Fig. 4-2). The 35-year mean discharge from Keenleyside based on this study is 1150 m^3/s.

Using statistical data on heads and discharges, numerous power studies were conducted to optimize installed capacity and compare alternative types of generating units (see Section 6.0). For Regime 1 and a nominal reservoir level of El. 424 at Murphy Creek, the optimum installed capacity was found to be 160 MW. The power study results for this case are as follows:

Installed Capacity	160 MW
Average Annual Energy, Total	600 GW.h
Average Annual Energy, Firm	530 GW.h
Average Annual Energy, Secondary	70 GW.h
Average Annual Spill	576 m^3/s
Average Annual Plant Downtime due to Insufficient Head	4.5 mo/yr

As indicated by the amount of spill - 50 percent of the available water (1150 m^3/s) - and by the amount of downtime, Regime 1 would result in very inefficient utilization of the water.

4.5 POWER STUDIES - REGIME 2

Regime 2 involves a reduction of about 2.5 x $10^9 m^3$ in the mean annual drawdown volume of the Arrow Lakes Reservoir and an increase of about 6.6 m in the mean annual minimum reservoir level. A summary of monthly mean reservoir levels, tailwater levels and discharges for Regime 2 is shown on Fig. 4-3.

For the 35-year simulation with Regime 2, mean downtime at Keenleyside due to insufficient head would be reduced from about 4.5 to 2.6 months per year and the Murphy Creek reservoir, in most years, would not have to be drawn down to permit the Keenleyside releases. Mean monthly discharges under Regime 2 would range from approximately 650 m^3/s (November) to 1600 m^3/s (February).

By drawing down the Murphy reservoir as the Arrow Lakes Reservoir is lowered, thereby maintaining the minimum 7.0 m gross head as required for the turbines, the operating period for the Keenleyside Powerplant could be further extended. However, because of the backwater effects in the very small Murphy Creek reservoir, the extent to which this could be done would be limited, after which the losses at Murphy Creek would exceed the gains at Keenleyside and Brilliant. In the present studies it has been assumed that 1.0 m of such drawdown of the tailwater level at Keenleyside would be utilized, reducing the mean annual downtime to about 2.4 months per year (see Fig. 4-4). On this basis the minimum Arrow Lakes Reservoir level for generation would be El. 430.0. Studies to optimize the amount of Murphy drawdown and the minimum Arrow Lakes Reservoir level for generation will be conducted during the next phase of studies.

Using statistical data on heads and discharges, power studies were conducted to optimize installed capacity. For Regime 2 and a nominal reservoir level of El. 424 for Murphy Creek, the optimum installed capacity was found to be 210 MW. The power study results for this case are as follows:

Installed Capacity	210 MW
Average Annual Energy, Total	880 GW.h
Average Annual Energy, Firm	830 GW.h
Average Annual Energy, Secondary	50 GW.h
Average Annual Spill	296 m^3/s

Average Annual Plant Downtime due to Insufficient Head	2.4 mo/yr

Compared to Regime 1, Regime 2 would result in a much more efficient operation. Spillage would be reduced from 50 to 26 percent of the available water and, with a capacity increase of 31 percent, average annual energy would be increased by 47 percent.

The head, discharge and monthly average power potential under Regime 2, are shown graphically on Fig. 4-4.

SECTION 5.0 - SITE GEOLOGY AND INVESTIGATIONS

5.1 SITE EXPLORATION PRIOR TO 1981

Foundation and construction materials investigations for the existing dam were carried out by various government agencies and private firms from 1949 to 1963.

During 1949 and 1951, 10 diamond holes totalling 470 m were drilled at the site by the Federal Department of Northern Affairs and National Resources. A seismic survey of the north shore of the Castlegar Narrows was also carried out in 1952.

In November 1960, CBA Engineering Ltd. was retained by the B.C. Power Commission to investigate the development of the Arrow Project. Foundation studies, including geologic mapping, drilling and seismic surveys were carried out at six different sites in the Castlegar Narrows area. Based on these studies, the present damsite was selected.

From 1960 to 1963, 130 exploratory holes totalling over 5600 m were drilled at or near the site by CBA Engineering Ltd. Of the total 140 holes drilled at the damsite by CBA and the Federal Government, only four are located within the proposed powerhouse area. About 30 holes are located in the general vicinity of the proposed powerhouse. These holes are shown on Fig. 5-1.

A comprehensive construction materials exploration program was also carried out by CBA Engineering Ltd. This program identified a concrete aggregate deposit on the left bank about 2 km upstream of the dam, which extended upstream for about 1 km. The upstream portion of the deposit was mined for the project.

The Balfour till pit (Borrow Area 9, see Fig. 9-3), was identified as a suitable source of impervious material. Material for the upstream impervious blanket and for the earth dam core was removed from this pit.

During construction of the dam, bedrock was exposed and partially excavated to provide a suitable foundation for the concrete structures. Some details of the bedrock surface were obtained from this work. In addition, information was obtained regarding geology, rock quality and rock conditions.

In addition to the 130 exploratory bore holes, 161 additional bore holes, including 1244 m of diamond coring, were drilled to define the bedrock profile along the cofferdam axis and to define areas requiring grouting at the navigation lock.

5.2 1981/82 SITE EXPLORATION PROGRAM

In 1981/82, exploratory investigations[12] were carried out at the site to provide data for preliminary design of the proposed powerplant. A large amount of information was already available from previous exploratory work. Therefore, the 1981/82 studies were designed to both verify existing information and obtain additional details about geology, foundation conditions and construction materials for the proposed powerhouse. This work was carried out on the left bank, both in the area of the proposed powerplant and at potential sources of construction materials.

In September 1981, five bore holes totalling 148 m were drilled on the left bank of the site. Casing was left in place and capped in each drill hole for future use as standpipes.

During May to August 1982, geologic mapping of the site was carried out and 17 bore holes totalling about 460 m were drilled at and around the proposed powerhouse location. Continuous, disturbed overburden samples were obtained and laboratory testing was done to assess the suitability of this material for use as construction material. Bedrock in each hole was confirmed by coring (NX size) about 5 m into rock.

Standpipes were installed in three holes to measure groundwater levels. The five 1981 drill holes were also adapted for use as open wells to measure groundwater levels. Permeability tests were carried out in overburden in drill holes DH 82-8 and 82-10.

The locations of the drill holes are shown on Fig. 5-1.

5.3 SITE GEOLOGY

(a) General

At all of the potential damsites examined in the Castlegar Narrows area by CBA Engineering Ltd., the foundation bedrock was found to be of excellent quality. Selection of the existing site was based primarily on the bedrock configuration. At this site, both abutments are alluvium but the buried bedrock ridge on the left side of the valley was found to have favourable dimensions and orientation for the concrete structures.

No rock outcrops exist within the proposed powerhouse outline. Bedrock is considered to be from 15 m to 30 m below the ground surface. A plan of the site geology, including interpreted bedrock contours, is shown on Fig. 5-1. Geologic sections of the site are shown on Figs. 5-2 and 5-3.

(b) Rock Types

The foundation bedrock at the site is granodiorite (locally grading to granite) of the Nelson plutonic rocks (refer to Section 2.3). The rock is of excellent quality and is very hard and generally fresh with very little weathering. Bedrock surfaces exposed during construction of the dam were found to be glacially smoothed and polished.

The rock is crystalline, with a texture ranging from a slightly foliated granodiorite to a thick-banded gneiss with prominent segregated layers of hornblende, feldspar and, locally, biotite mica.

Under the north bulkhead (Fig.3-1), the foliation strikes east-west and commonly dips southerly at 15° to 20°. However, under the north end of the north bulkhead and in rocks exposed in outcrops around the site the foliation strikes east-west and dips northerly at more than 45°.

During construction of the dam, a number of biotite layers up to 0.6 m thick and 20 m long were found in the dam foundation, particularly in the navigation lock area. Due to the softness of these layers they had been eroded by the river to depths of a few metres and had to be cleaned out and backfilled with concrete. Two of these biotite layers, dipping northerly at 30° to 45°, occur under the north bulkhead as shown on Fig. 5-2 and it is assumed they would extend below the proposed powerplant excavation.

(c) Bedrock Contours

Bedrock contours interpreted from drilling results and exposures during construction are shown on Fig. 5-1. The interpreted bedrock contours show that the buried bedrock ridge under the north bulkhead extends into the south end of the proposed powerplant excavation, which would have an invert level at about El. 392. The highest bedrock in this ridge is at about El. 430.

Bedrock drops off quite steeply to about El. 395 upstream of the ridge and about El. 385 downstream of the ridge. However, no deep throughgoing channel has been found below the proposed powerplant subgrade and it is expected that the structure would be founded entirely on bedrock. If any deep, narrow guts do exist, they would be cleaned out and backfilled with concrete.

(d) Discontinuities

The site rock is generally massive and relatively free of discontinuities. The features identified consist of joints, fractures and a few features referred to as faults in earlier reports. It should be noted that these "faults" are not major features.

(i) Joints

Most of the site rock is very sparsely jointed and the joints that are present are tight and discontinuous. Based on earlier work, most of the joints have been grouped into three sets:

1. Strike N to N20°E, dip 60° to 80°E.
2. Strike N10° to 20°W, dip 15° to 45°W.
3. Strike E-W, dip 90°.

Few joints were observed in outcrops around the site, but most fall within the above three sets. The most common appear to be those of set 3.

Based on experience at other sites with similar igneous bedrock, sheeting or exfoliation joints parallel to the bedrock surface could be expected. Such joints were not described in earlier reports and were not observed in outcrops at the site during recent geologic mapping. However, such joints can be incipient and would only show up during blasting.

(ii) Fractures

Earlier geologic mapping indicated that eight parallel vein-fracture zones with a trend of north to N10°E and an easterly dip of 55° to 80° exist under the north bulkhead. These fractures apparently contain hydrothermally-deposited quartz and, within 150 to 300 mm of the veins, the wallrocks are bleached, kaolinized and pyritized. Local slickensides and discontinuous gouge-like material up to 10 mm thick indicate that limited movement has occurred.

These fractures were not observed during recent geologic mapping or in drill holes, but it is reasonable to expect that some of those in the north bulkhead foundation rock may extend into the proposed powerplant excavation. Other parallel fractures are also likely to be present.

(iii) Faults

Two features referred to as the "East and West Faults" have been described by CBA Engineering Ltd.[13] The "East Fault" was not exposed but was defined by exploratory drilling. It trends about N20°E, downstream of the navigation lock, and would not occur near the proposed powerplant.

The "West Fault" was exposed during the dam construction in a trench upstream of the north bulkhead. It also strikes at about N20°E and may extend into the proposed powerhouse excavation. Despite being called a fault, the "West Fault" is more likely only a well developed vein-fracture zone and not a major fault.

(e) Rock Testing

In 1961, unconfined compression tests were carried out on 12 core samples from drill holes DH 111 and DH 123 in the navigation lock area. The samples were representative of four types of rock textures ranging from well foliated to massive, medium grained granodiorite. All samples were described as "sound rock".

An average unconfined compressive strength of 180 MPa, with a range from 121 MPa to 233 MPa, was recorded in these tests.

This is the only known rock testing that was carried out for the project. However, because of the excellent quality of the foundation rock, it is not considered necessary to carry out further rock mechanics testing for the proposed powerplant.

(f) Overburden

On the north bank of the site there are remnants of both the El. 425 and El. 520 terraces. Excavation for the proposed powerhouse would be mostly in the lower terrace, but would extend into the lower part of the upper terrace.

As shown by geologic sections on Figs. 5-2 and 5-3, part of the existing overburden around the north bulkhead above El. 425 consists of backfill material placed in the excavations for the original cofferdam and concrete dam. The results of the 1982 drilling program indicate that the backfill is mostly clean sand, gravel and cobbles.

The natural in situ overburden is also sand and gravel but is more variable in nature. Below about El. 425, much of the overburden is silty, especially near bedrock. The cobble content is quite variable and boulders occur randomly at all levels. A boulder layer up to several metres thick also occurs locally just above bedrock.

Based on constant head and falling head permeability tests in drill holes 82-8 and 82-10, the overburden has a permeability ranging from about 10^{-3} to 10^{-5} cm/s.

(g) Groundwater

Groundwater studies carried out during 1961 to 1964 indicated that the lower terrace deposits are relatively free-draining.

Groundwater was encountered in all 1982 holes during drilling. Standpipe open well measurements show that below the north bank park area, the groundwater level is nearly horizontal at about El. 430 m. Further into the slope, the groundwater level increases as the surface and bedrock topography rises.

There is little indication of a downstream gradient in the groundwater level around the north bulkhead.

Annual records of water levels in the two observation wells (Nos. 52 and 53, see Fig. 5-1) in the north bank show that ground water levels in this bank vary with reservoir level. The total annual fluctuation in the wells is about 4 m maximum compared with a headwater fluctuation of about 20 m.

5.4 GEOTECHNICAL FACTORS AFFECTING DESIGN

The site bedrock is of excellent quality and would provide a suitable foundation for the proposed powerhouse. Based on the interpreted bedrock contours, the powerhouse would be founded entirely on bedrock and would require removal of about 330 000 m³ of rock.

It is expected that, with controlled blasting techniques, neat rock walls could be excavated with little support. Local rock support may be required at points where vein-fracture systems intersect joint sets, or where steep joints parallel excavation walls. Once bedrock at the site is exposed, any discontinuities would be carefully mapped to determine if any special rock treatment is required.

The biotite layers which caused concern during construction of the existing dam have been described as fresh and tight except at surface, so they should not cause problems if encountered in the excavation.

Since the bedrock in the area is of excellent quality, with few discontinuities, quarries for riprap or rockfill could be established at any convenient site in the local area.

Sufficient quantities of suitable concrete aggregate and impervious materials for the project have been identified.

Overburden excavations for the powerplant would be in sand and gravel. Below El. 425, much of this material is silty. Since the present groundwater level is at about El. 430 and although the overburden has a low permeability, excavation below that level would likely require some form of dewatering or seepage control. Any seepage from the slope above the excavation would be intercepted and diverted.

No further exploration work is required for final design of the project.

5.5 SEISMIC ASSESSMENT

The 1970 Seismic Zone Map for Canada places the project area on the boundary of Seismic Zones 0 and 1, an area of very low to low earthquake hazard.

Seismic records for the area are available from 1899 to present and have been obtained from Energy, Mines and Resources Canada, Pacific Geoscience Centre (PGC). No earthquakes have been recorded within about 50 km of the site. The strongest earthquake recorded within 200 km is a magnitude 5.5 event, which occurred in 1942 about 170 km southeast of the project site.

Since 1899, the Keenleyside-Murphy area has experienced a maximum horizontal acceleration of 1 percent of gravity (below the human perception level of about 1 1/2 percent), caused by strong earthquakes in the West Coast-Puget Sound area and by lower magnitude earthquakes closer to the area. Using the Cornell risk estimation method, which is being adopted for the 1985 National Building Code of Canada, PGC has calculated that a peak horizontal acceleration of 5 percent gravity and a peak horizontal velocity of 5.5 cm/s have an annual probability of exceedance of 1:475. [The exceedence level of 1:475 will be adopted in the 1985 National Building Code.] Theoretically, a magnitude 6 earthquake at a distance of 60 km could induce such an acceleration and velocity at the project site according to PGC attenuation relationships. However, there are no fault systems within the 60 km radius of the project site that would have the potential to generate a magnitude 6 earthquake.

The closest regional fault system is about 200 km to the southwest. There are numerous less extensive faults in the area, mostly to the south and east, but there has been little recorded seismic activity associated with these faults.

The Arrow Lakes Reservoir behind Hugh Keenleyside Dam was filled in 1969. This did not cause any measurable increase in seismic activity.

Based on the nature of regional faulting and the recorded seismic history, a maximum credible earthquake of magnitude 6 is assumed for the area, and peak horizontal acceleration of 10 percent gravity (0.1g) has been adopted for design of major structures such as the dam and powerplant. The probability of having a magnitude 6 earthquake near the project site that would be capable of generating a peak horizontal acceleration of 10 percent gravity is, however, extremely small from the point of view of geotectonic considerations as there are no active faults near the site. However, this acceleration was used for the design of existing major structures at Hugh Keenleyside Dam and is consistent with ICOLD (International Congress on Large Dams) recommendations.

The design of ancillary structures is to conform to the requirements of the 1985 National Building Code and an acceleration of 5 percent gravity (0.05g) has been adopted (probability of exceedance of 1:475).

5.6 1982 CONSTRUCTION MATERIALS INVESTIGATIONS

(a) General

The estimated construction materials requirements for the proposed project are:

Impervious material (glacial till)	150 000 m^3
Processed concrete aggregate material	200 000 m^3
Rockfill and riprap	240 000 m^3

If the core of the downstream cofferdam is constructed of silty sand and gravel, the till requirement would decrease to 100 000 m^3 and 50 000 m^3 of silty sand and gravel would be required. Most of the rockfill would be obtained from the powerplant excavation. However, it is estimated that about 50 000 m^3 could be required from a rock quarry. The rock quarry, if required, would be located in Area 8 about 2 km upstream of the dam on the left bank (Fig. 9-3).

In 1982, a construction materials investigation program was carried out in Borrow Areas 3, 6 and 9 as shown on Fig. 9-3. Borrow Area 3 is the proposed powerhouse site.

A Becker hammer drill rig was used to obtain continuous disturbed samples in seven drill holes totalling 163.5 m in Area 6, a proposed concrete aggregate source. In addition, test pits up to 10 m deep were excavated adjacent to three of these drill holes. Disturbed samples for laboratory testing were collected from selected horizons in drill holes and test pits.

In 1983 a small program was carried out in Area 4 to examine material in this area as a supplement to aggregate from Area 6, if required. Ten test pits up to 8 m deep were excavated with samples collected for laboratory analysis.

To assess the quantity and quality of the impervious material in Borrow Area 9 (Balfour Till Pit), ten test pits were excavated. Disturbed samples for laboratory testing were taken from the faces of the excavations.

(b) Borrow Area 3

This area encompasses the proposed powerplant excavation on the left abutment of the dam as shown on Figs. 5-1 and 9-3. The overburden in this area is described in Section 5.3(f).

The backfill material in this area, consisting of a mixture of sand, gravel, cobbles and boulders, extends to a maximum depth of 34 m.

Area 3 contains about 150 000 m^3 of unprocessed sand and gravel that would be suitable for use as concrete aggregate or granular fill. Local lenses of silty material encountered during drilling would have to be wasted. Outside and below the original backfill, the natural material tends to be too silty for use as concrete aggregate.

(c) Borrow Area 4

Area 4 was examined in April 1983 as a potential supplementary source of concrete aggregate. The area is a ramp which was constructed to facilitate placement of the existing impervious blanket. The location of the ramp is shown on Fig. 9-3. Based on visual inspection, the material appears to be generally a well-graded sand and gravel. Disturbed samples have been shipped to the laboratory for testing.

(d) Borrow Area 6

This area lies on the eastern boundary of the original concrete aggregate pit for the Hugh Keenleyside Dam. Its location is shown on Fig. 9-3.

The drill holes and test pits (Fig. 5-4) indicate that well graded sand and gravel extends to about El. 432.5. Below this elevation there is a mixture of sand and silt.

The material encountered in drill holes DH 82-603 and DH 82-604 and test pit TP82-608 is fill consisting of silty sand and gravel, large angular cobbles and boulders and wood chips. This material would not be suitable for use as concrete aggregate.

Area 6 contains about 260 000 m^3 of unprocessed sand and gravel suitable for use as concrete aggregate. This quantity should fulfill the major requirements; however, additional material could be obtained from Area 3, or possibly Area 4.

(e) Borrow Area 9 (Balfour Pit)

Area 9 is located approximately 4 km east of the dam on the left side of the valley at about El. 700 as shown on Fig. 9-3. This area was the original source for till used in the dam core and upstream blanket.

This till deposit (see also Fig. 5-4) is variable in thickness due to the irregular bedrock topography. The depth to bedrock varies between 1 m and 10 m. Two separate discontinuous till units are present throughout the area, with a red-brown till generally overlying a grey till. The properties of both tills are similar, the grey till tending to have a slightly higher silt content.

The till is non-plastic and generally well graded. It has an average silt content (percent passing No. 200) of 29 percent and clay content of 4 percent. The average maximum dry density and optimum moisture content from the Standard Proctor test are 2035 kg/m^3 and 8.8 percent respectively.

The in situ moisture content varies considerably but on average is about 2 percent wet of optimum, ranging locally from -3 percent to +7 percent from optimum.

The till would be suitable for use as blanket material for the new construction. Although selective borrow operations may be necessary due to varying moisture content, the only processing required should be the removal of oversize boulders.

Area 9 contains approximately 400 000 m^3 of impervious material and would fulfill the requirements for proposed blanket and cofferdam material.

SECTION 6.0 - PROJECT ARRANGEMENT STUDIES

6.1 ALTERNATIVE PROJECT ARRANGEMENTS

During the Prefeasibility Study[3] consideration was given to three alternative project arrangements, all based on a nominal reservoir level of El. 427 for the Murphy Creek Project and an operating Regime essentially the same as Regime 1.

Alternative 1

Alternative 1, the port arrangement, would utilize four of the eight low level ports as intakes for two horizontal shaft generating units. The physical dimensions of the four ports would limit the generating capacity to 68 MW based on Murphy 427 (see Fig. 6-1) or about 88 MW based on Murphy 424. As these capacities were only about 55 percent of the optimum (for Regime 1) and because of anticipated cofferdamming difficulties in the sluiceway and the inability to meet discharges required under the Treaty, this alternative was considered unattractive and was abandoned.

Alternative 2

Alternative 2, the canal arrangement shown on Fig. 6-2, would involve a 900 m long canal located on the left bank beyond the existing impervious blanket. This arrangement would minimize disturbance to the blanket. By staging the canal entrance, cofferdamming upstream of the existing dam also would have been minimized. However, the cost of the canal scheme was found to be about 8 percent higher than Alternative 3, the selected short channel arrangement.

During the Phase 1 Preliminary Design Studies, the canal scheme was briefly re-examined as it would provide superior flow conditions in the vicinity of the powerplant intakes. However, with the change from Murphy 427 to Murphy 424 and the resulting increase in capacity and lowering of the minimum Arrow Lakes Reservoir elevation for generation, the canal would have to be greatly deepened and enlarged. On the basis of this canal re-examination it has been confirmed that the canal scheme would not be economic. The reasons are as follows:

1. Based on an installed capacity of 210 MW and Murphy 424, the additional cost for the canal arrangement compared to the proposed short channel arrangement is estimated at a minimum of $32 million (about 11 percent of total construction cost) excluding corporate overhead and interest during construction. The present value of the benefits resulting from improved flow conditions and higher turbine efficiency are estimated to be in the order of $3 to 6 million.

2. Based on site investigations and geotechnical design studies conducted since the Prefeasibility Study, the original canal design appears to be based on overly optimistic assumptions. It is probable that the canal side slopes would have to be flattened, further increasing the costs.

Alternative 3

Alternative 3, the proposed short channel arrangement, is shown on Fig. 6-3 and described in detail in Section 8.0. It is by far the most economical arrangement for adding generating facilities at Keenleyside. However, as discussed in Section 7.0, intake approach flow conditions are not ideal. For horizontal shaft units in particular, it would be desirable to have the flow approach the intakes at an angle within a few degrees of normal (90° to the face of the intakes). A brief study was therefore conducted to estimate the cost of rotating the powerhouse about 70° counterclockwise from its proposed alignment parallel to the existing dam axis. This study indicated that the additional cost would be in excess of $23 million. With Kaplan turbines, the present value of the benefits due to higher turbine efficiency (approximately 0.5 to 1.0 percent based on studies of The Dalles) are estimated at only $3 to 6 million and this benefit would likely be reduced by additional hydraulic losses in the tailrace channel. Rotation of the powerplant, therefore, could not be justified.

6.2 ALTERNATIVE TURBINE TYPES

In the Prefeasibility Study,[3] consideration was given to only one type of unit, horizontal shaft, straight flow units with rim-type generators (Straflo units). One of the first tasks carried out during the Phase 1 Preliminary Design Studies was to make detailed comparisons of horizontal shaft Straflo and bulb units with more conventional vertical shaft Kaplan turbines.

The first unit type comparison was made in early 1982 based on a total installed capacity of 150 MW. At that time the 150 MW capacity was roughly estimated to be optimum under Operating Regime 1. The comparison was made for the following arrangements:

Horizontal Shaft Units:

Bulb: 3 - 50 MW units
Straflo: 4 - 37.5 MW units

Vertical Shaft Units:

Kaplan: 2 - 75 MW units

The cost estimates prepared for these three alternatives had to be adjusted for the differences in overall plant efficiency. For the bulb units it was estimated that the overall plant efficiency would be about

3 percent lower than for vertical shaft Kaplan units, with 1.5 percent attributed to the turbine and 1.5 percent to the generator. The Straflo units were also estimated to be 3 percent lower in overall efficiency than the vertical Kaplan units as they would have fixed blade propeller turbines compared to the adjustable blades of the Kaplan turbines.

On the basis of total construction costs (October 1981 price levels) excluding corporate overhead and interest during construction and including efficiency adjustments (as a present value), vertical shaft Kaplan units were found to have an economic advantage of about $25 million or 11 percent over either of the horizontal shaft alternatives. The difference in assumed efficiency accounted for about 50 percent of the economic advantage.

With the change from Operating Regime 1 to Regime 2, the optimum installed capacity was increased from 150 or 160 MW to 210 MW. Because of the increased capacity and number of units, differences in the required construction periods, and because there were some differences in the arrangements used for the first comparison, it was considered desirable to make a further comparison of horizontal and vertical shaft machines. This was done in late 1982.

Detailed layouts and cost estimates were prepared for two new arrangements: a vertical shaft Kaplan arrangement having three 70 MW units (Fig. 6-3) and a horizontal shaft bulb arrangement having four 50 MW units (Fig. 6-4). The costs and benefits of the 210 MW Kaplan arrangement were then scaled down to 200 MW to permit comparison with the bulb arrangement. Results of the second cost comparison are shown on Table 6-1. The present value of net annual benefits was found to be $24.2 million higher with vertical shaft Kaplan turbines.

On the basis of the above comparison, studies of horizontal shaft units for Keenleyside Powerplant were discontinued.

6.3 CAPACITY OPTIMIZATION (KAPLAN UNITS)

The proposed Keenleyside Powerplant capacity of 210 MW was selected on the basis of maximized net annual benefits[14] as follows:

1. Construction Costs - Incremental construction costs (based on October 1981 price levels) were estimated on the basis of the detailed layouts and cost estimates prepared for the vertical shaft Kaplan arrangement having two 75 MW units (see Section 6.2).

2. Annual Costs - The annual costs were assumed as 4.6 percent of the construction costs. The factor of 4.6 percent was based on a net interest rate of 3 percent and included allowances for interest, depreciation, corporate overhead, interest during construction plus operating and maintenance costs. Annual water fees or rentals and property taxes were not included.

3. Annual Benefits - Energy and capacity values at the powerplant site (based on October 1981 price levels) were as follows:

Firm energy	23.0 mills/kW.h
Secondary energy	17.2 mills/kW.h
Dependable capacity	$8.61/kW/a

   Firm energy is the energy that could have been produced during the critical drought on the B.C. Hydro system, which corresponds to the historic streamflow record from September 1942 to April 1946.

   Secondary energy is the 35-year (1940-1975) average annual energy minus the firm energy.

   Dependable capacity, for Keenleyside, is the capacity available with an Arrow Lakes Reservoir drawdown condition corresponding to January 1945 historic streamflow conditions.

4. Results

Fig. 6-5 shows net annual benefits as a function of total installed generating capacity. Based on the costs and values of benefits as defined above, the net annual benefits of the Keenleyside Powerplant would peak at $7.92 million with an installed capacity of 210 MW.

SECTION 7.0 - HYDRAULIC STUDIES

7.1 GENERAL

The least cost alternative for the Keenleyside Powerplant comprises a short approach channel on the left abutment immediately upstream of the existing concrete dam, with the powerhouse forming an extension to the existing north bulkhead section (Fig. 6-3). This arrangement requires the approach flow to make two acute angle turns into the power intakes and thereby induces circulatory motion in the approach flow. Questions were raised about the possible effects of these undesirable flow conditions on the mechanical performance of the turbine and also on the overall efficiency of the plant.

To investigate these questions, or possibly quantify the adverse effects, a literature search was carried out to study existing powerplants with asymmetrical approach flow conditions and the measures, if any, used to improve the flow conditions. The plants included in these studies were Davis Dam, Boundary Project, Grand Coulee, The Dalles, Box Canyon and the proposed Site C Project on the Peace River. The plants having long penstocks between the intakes and turbines (such as Grand Coulee and the proposed Site C Project) were examined primarily for data on vorticity whereas the other plants, particularly The Dalles, were examined for data on intake flow and velocity distribution plus effects on overall plant efficiency. Where available, the model studies for these projects were examined and, where possible, the performance of the prototypes was discussed with the engineers and operating staff. The performance of all the constructed plants was generally reported to be good, including those which had worse approach conditions than the proposed Keenleyside Powerplant, but it was not possible to precisely quantify the effects of these conditions.

Potential turbine suppliers were contacted but, while expressing concern over flow conditions in the proposed powerplant arrangement, they were unable to quantify their concern without extensive turbine model tests. Because of the substantial economic advantage over alternative arrangements (Section 6.1), a decision was made to proceed with comprehensive hydraulic model studies of the short channel arrangement (Fig. 6-3). Efforts to improve the flow conditions would be made during both the Phase 1 and Phase 2 preliminary design and hydraulic model studies.

The Dalles Project provided the most useful information including model results on a 1:80 scale comprehensvie model followed by additional studies on a 1:25 scale simulation of one of the 14 Kaplan units comprising the initial installation. On this latter model, examinations were made of the effects of various angles of approach flow on the velocity distribution pattern observed within the intake at the entrance to the scroll case. In addition, the flow distribution through the wicket gates at the downstream end of the semi-spiral case was also recorded. The effect of the angle of approach on the velocity distribution patterns as well as on the flow distribution through the wicket gates was found to be very minor. Some of these model techniques, developed on The Dalles model, were later used on the Keenleyside model as described in Section 7.2.

Approach flow conditions at The Dalles are much more severe than those expected at Keenleyside Powerplant. Approach flow angles at the face of the powerplant intakes range from 0° to about 65°, as measured from the normal (90° to intake face), compared to about 15° to 20° at Keenleyside. Velocity distribution within the intakes is also much more varied.

Based on current meter tests of prototype efficiency at The Dalles, a rough approximation of the effect of asymmetrical flow conditions on the overall powerplant efficiency at Keenleyside was made by comparing the measured efficiencies of all the initial 14 units at The Dalles. It was estimated that the loss in efficiency at Keenleyside due to unfavourable approach flow conditions would not be more than about 0.5 to 1.0 percent.

7.2 HYDRAULIC MODEL STUDIES

The hydraulic model studies[15] were carried out at the Northwest Hydraulic Consultants Laboratory (NHCL) in North Vancouver on a comprehensive model at a scale of 1:100. The extent of the area modelled is shown in Fig. 7-1.

(a) Approach Channel

The preliminary elevation of the sill dividing the forebay from the reservoir was at El. 425 and this elevation continued towards the powerhouse to a line equidistant in all directions from the powerhouse. From this line at El. 425, the bed dropped to the elevation of the debris trap in front of the intakes at a uniform slope of 1V:4H. This wide sill configuration produced a variable velocity distribution across the extended entrance sill, with the highest velocities located close to the dam and reducing significantly in a clockwise direction from the dam. This velocity distribution tended to increase the obliquity of the approach flow.

The approach channel configuration in the model was modified by lowering the sill level by 2.0 m to El. 423.0 and reducing its width to a constant 20 m (Figs. 7-1 and 8-1). From the downstream edge of this narrower sill the approach channel invert was sloped downward to the debris trap at a varying gradient producing a warped entrance with minimum changes in velocity. The velocity distribution in the flow approaching the powerplant was much improved by this measure.

Further improvement in the approach flow conditions, particularly near Unit 3, was achieved by adding a pier-shaped training wall on the face of the north bulkhead adjacent to Unit 3. This training wall changed the extremely oblique approach angle at Unit 3 to about the same angle observed upstream of the other two units.

Observations were made of the tendency for vortices to form in front of the intakes. The only place where any vorticity was observed was in front of the right bay of Intake 3, adjacent to the training wall. With the reservoir at El. 430 (minimum reservoir for powerplant operation), the flow, at times, tended to develop a vortex and a swirl formed. However, the surface did not form a dimple nor did dye injected below the surface show a vortex line. At higher reservoir levels the tendency was more frequent and a slight dimple formed. Operating the spillway increased the frequency with which vortices started to develop but only slight dimples were generated. This vortex development is considered too low to cause any difficulties with the prototype. This observation was confirmed also for model operation at twice the true Froude similitude value.

With the design of the approach channel modified as above it appears that further improvement in the flow conditions are unlikely unless the present constraints on the areal extent and sill elevation of the approach channel can be overcome. The existing topography of the impervious blanket limits the width of the approach channel entrance and the upstream cofferdam design limits how low the sill elevation can be set.

(b) Powerplant Intake and Trashrack

The configuration of the model powerplant intake is shown in Fig. 7-2 and corresponds to a standard elliptical entrance shape for surfaces flared in a single plane. Curvature on the upstream ends of the pier sides as shown on Plate 8-16 was not modelled. Velocities in the intake were measured at the vertical plane of the entrance (immediately upstream of the trashracks) and at a vertical plane 14 m downstream of the intake entrance (Section A-A in Fig. 7-2). The measurements at Section A-A are the most significant in terms of turbine performance, and are generally the values referred to below.

Other model tests have shown that the vertical rectangular bars of the trashracks can act as turning vanes. They can cause the oblique approach flow to turn uniformly so that it enters the intakes without large separation zones on the lee sides of the piers.

For the final approach channel configuration used on the model, Fig. 7-3 shows the velocities measured at Section A-A with and without trashracks. This figure shows nine velocity observations in each bay with the reservoir at El. 430. Without trashracks the velocities were highest at the top and at the left (looking downstream) of each bay. Velocities averaged 1.91 m/s for the left side of all bays and 1.27 m/s for the right side, a difference of 51 percent. With trashracks in place, the velocities were much more uniform left to right but still higher at the top. Velocities averaged 1.72 m/s for the left side of all bays and 1.52 m/s for the right side, a difference of 13 percent. Deeper trashrack bars would probably improve this further.

The model trashracks were made coarse for practical modelling reasons, and proportionately deeper than usual for better turning characteristics. A bar depth (in the direction of flow) to spacing ratio of 1.0 was adopted on the model but a larger ratio of 1.5 to 2.0 was recommended for the prototype to produce more uniform flow conditions.

The vertical variation in the intake velocities appeared to be due mainly to the high setting of the distributor relative to the intake passages and partly to lower boundary effects with open channel characteristics not yet replaced by pressure flow characteristics.

Fig. 7-3 also shows that Bay A of Unit No. 1 (farthest from the reservoir) received appreciably less flow (about 10 percent less) than Bays B and C. A short guidewall was placed immediately to the left of Bay A to help direct the flow into that bay but it did not improve the condition. The reduced flow appears to be due to the adjacent back eddy to the left of the intake. No further action was taken during the model study to correct this condition and the guidewall is not recommended.

(c) Powerhouse Rotation

The average flow approach angle, measured 18 m upstream of the intake face, for the proposed powerhouse orientation is about 45° from normal. Preliminary tests were carried out using long guidewalls to direct the flow into Unit 3 at 45°, 30° and 15° from normal. As bays A and C were affected to some extent by the guidewalls, Bay B best reflected the effect of the approach angle.

For an approach angle of 45° there was a 15 percent difference between the weighted average velocities on the left and right sides of the bay. For 30° and 15° the differences were 9 percent and 6 percent, respectively. Compared to the improvement made by the trashracks (51 percent to 13 percent), the improvement to be gained by rotating the powerhouse is small and is not expected to be cost-effective. It was concluded that, without rotating the powerhouse, satisfactory velocity distribution could be achieved more economically with care in the design of the trashracks and piers.

(d) Distributor Location

The higher velocities near the roof (nearly twice the velocities at the floor) of the intakes in the original model were attributed in large part to the high location of the distributor with respect to the intake (see Fig. 7-2). To correct this, the intake was initially raised by 3 m with respect to the distributor (to model the effect of lowering the distributor), after first checking that the reduced submergence did not induce vortices. The vertical velocity distribution at Section A-A was much improved with this arrangement. At about this time it became apparent that lowering of the distributor by 3 m would be beneficial in reducing the dependence of the Keenleyside Powerplant on the downstream Murphy Creek Project, would accommodate a larger drawdown at Murphy Creek, and would permit increased generation in the period before Murphy Creek would be in service. The model intake was therefore returned to its original lower location and the distributor was then lowered by 3 m. A small flair was also added to the entrance floor which eliminated a separation zone. The vertical velocity distribution improved markedly.

Fig. 7-4 shows 25 velocity measurements per bay for three different reservoir levels with the final intake and distributor configuration and with trashracks in place. For the reservoir at El. 430 the intake velocities averaged 1.67 m/s near the roof and 1.56 m/s near the floor, a difference of only 7 percent. The flow distribution between the bays was fairly uniform except at Bay A of Unit 1 (farthest from the reservoir) where velocities were still consistently low by about 10 percent.

(e) Tailrace Channel Studies

Initially the tailrace channel studies examined the effect of spillway/port operation on water elevations in the tailrace channel and particularly at the draft tube exits. Representative spillway/port discharges were obtained from the system power studies for simulation on the model, and equipment was installed to record the waves generated by this operation in the tailrace channel. Waves generated by the sluiceway spill were largely suppressed at the exit of the tailrace channel by the powerplant discharge. However, a small surge with a frequency of about 0.01 Hz (100 second wave period) persisted into the tailrace channel at larger sluiceway discharges. This will be checked against the natural frequency of the generating units as their design proceeds further.

Until completion of the Murphy Creek project, tailwater elevations at Keenleyside must be raised artifically to maintain a minimum submergence of the units. Calculations showed that a weir with a crest level of El. 416.5 across the width of the tailrace channel would provide the necessary submergence with one unit only operating. The model studies were required to investigate the required weir configuration to provide the necessary submergence for single unit operation but minimize the head loss at higher powerhouse discharges.

The model studies showed that these conditions were satisfied best with a long weir across the entire tailrace channel and extending to and sealing against the north bulkhead of the existing dam. The crest level of this weir was established at El. 418.2. The energy benefits from the reduced head losses for this long weir, at two and three unit operation, were found to exceed the cost of the extra excavation required outside the limits of the tailrace channel.

It was observed during the preliminary studies that, at high sluiceway and powerplant discharges, tailwater elevations in the vicinity of the sluiceway and exit from the tailrace channel were higher than expected. Most of this increase in water elevation was caused by the constriction between the left bank and the rock groin located downstream from the lock.

Detailed studies of losses throughout the tailrace system (draft tube exit to beyond the rockfill groin) concluded that, for powerhouse operation alone, most of the losses occurred near the powerhouse. The loss at the constriction created by the rockfill groin was negligible with powerplant discharge only. It was concluded, therefore, that channel improvement at the constriction was not warranted. However, optimization studies to reduce the tailrace channel losses close to the powerhouse will be carried out in the Phase 2 studies.

The total head losses through the powerplant, excluding the scroll case, distributor and draft tube friction losses normally attributed to the turbine, are estimated to vary from 0.39 m for Unit 3 to 0.54 m for Unit 1. These losses are based on full gate rated discharge of approximately 500 m^3/s per unit with a full reservoir and a normal tailwater level of El. 424. They include an entrance and trashrack loss estimated at 0.05 m for each unit, a draft tube exit loss (velocity head) of 0.29 m for each unit, and tailrace channel losses ranging from 0.05 m (Unit 3) to 0.20 m (Unit 1). The varying tailrace channel loss results from the spatially varied flow in the sharp bend immediately downstream of the powerhouse where a relatively steep gradient between Unit 1 and Unit 3 is required to establish flow out of the channel.

SECTION 8.0 - PROPOSED PROJECT ARRANGEMENT

8.1 GENERAL

The proposed project arrangement for the Keenleyside Powerplant is shown on Figs. 8-1 and 8-2. The three-unit powerplant would be connected to the end of the existing north bulkhead by means of a 10 m long gravity dam section. A service bay would be provided at the north end of the powerplant and would be followed by another short section of gravity dam. These structures would facilitate a complete cutoff to rock up to the crest level of the dam.

Water would be conducted to the powerplant in a short approach channel sloping downward from a sill level at El. 423.0 and would be returned to the river via a tailrace channel excavated to an invert level of El. 412.0.

The major project components, including cofferdams, are described below. Further refinement of individual project components will be carried out during Phase 2 of the Preliminary Design study.

8.2 COFFERDAMS

Dewatering of the construction area for the Keenleyside Powerplant would be accomplished by constructing cofferdams upstream and downstream of the existing north bulkhead structure. Earth-rockfill cofferdams have been tentatively selected and are shown on Fig. 8-3. A concrete cutoff wall alternative for the downstream cofferdam has also been studied. Selection of the arrangement for the downstream cofferdam will be made along with the design optimizations and a flood risk analysis during the Phase 2 studies.

The alignment of the upstream cofferdam would permit connection of the new approach channel impervious blanket to the existing blanket in the dry. A large portion of the approach channel would also be completed behind the cofferdam. One way public traffic would be accommodated during construction along a road on the 5 m wide crest of the cofferdam.

The alignment of the downstream cofferdam provides the shortest length of cofferdam while maintaining sufficient clearance for powerhouse construction. The 4 m wide crest will provide access for maintenance only.

(a) Upstream Cofferdam

The construction sequence for the upstream cofferdam is shown on Fig. 8-5.

The existing Hugh Keenleyside earthfill dam was constructed with an impervious till blanket extending 685 m upstream of the dam axis and rising to El. 443.7 on the north and south banks of the reservoir. A portion of the existing blanket was constructed behind a cofferdam. The axis of this original cofferdam in the area of the new construction is shown on Fig. 8-4. It incorporated a concrete cutoff wall to bedrock which was left in place following construction.

The Hugh Keenleyside earthfill dam and some of the upstream blanket outside the original cofferdam was constructed in the wet.

Stage 1 excavation for the upstream cofferdam intercepts the existing till blanket such that the till core of the cofferdam can be connected to the existing blanket. To minimize underwater work the excavation would have to be completed when the reservoir is near the lowest level (El. 419.6) of the annual drawdown period.

The foundation material under the upstream cofferdam would consist mainly of the original till blanket about 4 m thick overlying original overburden. The main portion of the new cofferdam would be placed on material originally placed and compacted in the dry behind the original cofferdam.

Excavated materials would include riprap, riprap bedding and sand and gravel originally placed to protect the north slope. Excavated riprap material would be dumped over the outer slope to form part of the lower portion (below El. 422) of the cofferdam. Sand and gravel from the excavation would be used as fill material where required.

Conventional rolled fill methods would be used to complete the cofferdam in the dry to a crest elevation of 442.0 m. The sloping core would facilitate cutting the cofferdam down to form a dyke for the blanket connection. To increase the seepage path the core would be widened where it contacts the existing north bulkhead concrete structure.

The upstream cofferdam would be tested at high reservoir level before the existing till blanket is breached and before excavation for the approach channel and powerhouse progresses below the cofferdam crest level (Fig. 8-5, Stage 2). However, excavation for the downstream cofferdam would be allowed to proceed before completion of the upstream cofferdam.

The construction sequence (Fig. 8-5, Stage 3) illustrates how the approach channel and powerhouse excavation would form the lower portion of the upstream cofferdam. A bench could be constructed on this slope to accommodate a dewatering system, if required.

The five high pipe drains (Fig. 8-5, Stage 3), originally installed under the blanket to reduce high pressures known to exist in the north bank, with the exception of drain 234, would not be disturbed during the initial powerhouse construction period. The low drains also would be left undisturbed.

Instrumentation would be installed in the cofferdam to monitor movement, settlement and pore pressure during and after construction.

(b) Downstream Cofferdam

The arrangement of the downstream earth-rockfill cofferdam is shown on Fig. 8-6 and the construction sequence on Fig. 8-7. The existing abutment slope consists of heavy rock blocks on riprap and riprap bedding over-lying selected sand and gravel. The first stage of the cofferdam construction requires a tailwater level at or below El. 420.0 for excavation to bedrock and construction of the underwater portion of the cofferdam. The rockfill portion of the excavation would be used to construct a rockfill dyke to above water level (approx. El. 420.0). This dyke would create a pond protected from turbulent flows from the low level ports and sluiceways. The dyke would be positioned so that a minimum 10 m wide core could be placed at the bedrock contact surface.

Excavation below water level would progress from the downstream face of the north bulkhead to the outer end of the cofferdam. The filling operation would commence at the outer end and progress towards the north bulkhead.

Glacial till would be dumped behind the rockfill dyke, through standing water in the central portion of the excavation to form the cofferdam core, which would be in contact with bedrock.

Above water level, conventional rolled fill methods would complete the cofferdam to a crest level of El. 428. This crest elevation would provide sufficient freeboard, allowing for settlement of the crest, to resist overtopping by waves created by discharges from the existing facilities.

The construction sequence shown on Fig. 8-7 illustrates how the powerhouse excavation would form the lower portion of the downstream cofferdam. The excavation would leave a minimum 3 m clearance for powerhouse construction. Seepage flows into the unwatered area would be handled by pumping.

The downstream cofferdam would be instrumented to monitor movements, settlement and pore pressures during and after construction.

8.3 APPROACH CHANNEL

The approach channel is shown on Fig. 8-8. As described in Section 8.2(a), the excavation for the major portion of the approach channel would be done behind the upstream cofferdam as shown on Fig. 8-5, Stage 3. Excavation for the approach channel at this stage would expose part of the old cofferdam and cutoff wall.

The exposed portion of the cutoff wall would be removed to 1 m below the base of the new blanket excavation. Connection of the remaining wall to the new blanket would be accomplished by over-excavating on both sides of the wall and backfilling with impervious blanket material (Fig. 8-5, Section A).

To ensure that seepage under the blanket is controlled when the approach channel is completed, an impervious till blanket would be placed over the surface of the new approach channel.[16]

Section B on Fig. 8-8 illustrates how the upstream cofferdam would be removed as the reservoir is lowered below El. 430. The portion of cofferdam remaining would form, due to the geometry of its sloping core, a dyke which would enable the blanket connection to be made in the dry when the reservoir level is below about El. 428. Excavation for the blanket connection would expose the high pipe drains, originally installed under the existing impervious blanket to relieve high pressures in the north bank. These pipes would be cut, relocated and restored to operating condition.

The new impervious till blanket would be installed over the surface of the approach channel as shown on Fig. 8-8, Section A. The thickness would vary from top to bottom of the slope with a minimum thickness of 3 m. Slope protection consisting of a 1 m thick layer of riprap and riprap bedding would be provided over the channel surface.

Security of the blanket in the limited area of steeper slopes would be ensured by over-excavating the area and placing the blanket deeper in the slope, then backfilling to the final channel grade with free draining material.

The completed approach channel would be as shown in the plan on Fig. 8-8.

8.4 TAILRACE AND TAILRACE WEIR

The downstream cofferdam would be modified after completion of the powerhouse to form a weir which would provide the required submergence for the turbines until the downstream Murphy Creek Project is constructed.

A plan and typical section of the weir is shown on Fig. 8-9. The geometry of the weir was determined from hydraulic model tests. The outer face of the weir would follow the alignment of the rockfill dyke of the downstream cofferdam. The 15 m wide crest of the weir would be protected by a layer of riprap. The tailrace would be flooded during removal of the cofferdam and a large portion of the excavation would have to be accomplished under water.

The tailrace channel, excavated and completed to final grade after completion of the Murphy Creek Project, is shown on Fig. 8-8. Slope and channel protection would be provided by a layer of riprap approximately 1.0 m thick over the invert and slopes of the final channel. This work should be done during a period of lowest possible tailwater levels.

8.5 HIGHWAY RELOCATION AND ACCESS ROADS

The general arrangement for the relocated highway and access roads to the dam crest and powerhouse yard is shown on Fig. 8-10.

The relocated highway would conform to the requirements of the B.C. Provincial Ministry of Transportation and Highways' standards. No bridges would be required.

The dam crest and powerhouse yard are each connected directly to the relocated highway by access roads about 20 m and 100 m in length, respectively.

Typical sections for the relocated highway are shown on Fig. 8-10. Side slopes adopted for rock and overburden materials are 1H:4V and 1.5H:1V respectively. Geological investigations indicated that the rock slope adopted is conservative and side slopes in rock could be constructed steeper. Overburden materials are generally a mixture of silts, sands and gravels. The slopes adopted are generally considered satisfactory, except for some areas containing silts and fine sands. Additional stabilization measures may be required in these areas.

8.6 POWERPLANT

(a) Powerhouse Structure

The indoor powerhouse, with three 70 MW generators and Kaplan turbines, would be an extension of the existing north bulkhead structure and would be about 115 m long, including the service bay (see Figs. 8-2 and 8-11 to 8-19). A gravity transition section would be provided at both sides of the powerhouse. All new structures would be founded on bedrock.

A semi-outdoor powerhouse building using a gantry crane with retractable curtain walls was rejected as the cost saving over a conventional superstructure would be outweighed by difficulties in providing the required weather protection.

Following a cost comparison with cast-in-place reinforced concrete, a structural steel superstructure was selected. Cladding would consist of pre-cast, hollow core, insulated concrete panels. This type of cladding would provide the building with efficient thermal insulation.

A 23.5 m long by 23.5 m wide service bay, located at the north end of the unit bays, would provide sufficient space in conjunction with the adjacent Unit 1 floor area to allow simultaneous assembly of one generator rotor and one Kaplan turbine runner.

The intake for each unit would be integral with the powerhouse structure and would consist of three water passages separated by piers with trashracks at the upstream end.

At the intake entrance the roof, walls and invert slab would be curved to improve flow velocity distribution.

The draft tube for each unit would consist of three passages separated by piers with gates located at their downstream end.

Foundation drainage, similar to that provided for the existing structures, would be provided.

(b) Gates and Cranes

The intake gates would comprise one set of three bulkhead gates for closure of a single unit, and three sets of three hydraulic operating gates (one set for each of the three units).

Servicing of the intake gates would be accomplished using the existing 82 t sluiceway gantry crane modified to accommodate the taller, power intake gates. An extension of the existing rails would be required along the sloped deck of the north bulkhead structure, to connect with the new powerhouse rails. A jib with 3/4 m^3 capacity hydraulic grapple would be provided on the upstream side of the gantry crane for removal of forebay trash.

For draft tube closure three sets of three gates (for all three units) would be provided. The draft tube gates would be operated with a 50 t gantry crane.

The generating units would be serviced by two 250 t bridge cranes, operating throughout the full length of powerhouse. The two cranes, operating in tandem, would be capable of lifting a complete rotor.

(c) Turbines

The three vertical shaft Kaplan turbines, with runner diameters of approximately 8.2 m, would operate at 66.7 rpm and develop their rated output of 71 100 kW at a net head of 16.0 m. The rated discharge of each unit would be approximately 500 m^3/s. Because of the head range limitations of the turbines, it has been assumed that the plant would be shut down when the gross head is less than 7 m. The turbine ratings include allowances for surcharging the Arrow Lakes Reservoir from El. 440.1 to 440.7 in years of high runoff.

(d) Generators

Each of the three turbines would be coupled to an umbrella or semi-umbrella type generator with a synchronous speed of 66.7 rpm and rated 70 MW at 13.8 kV, 0.90 power factor. Each generator would be connected by naturally cooled isolated phase bus to a three-phase generator transformer rated 80 MVA, 13.8 kV to 230 kV, installed on the tailrace deck.

(e) Transformers and Switching Equipment

Generator circuit breakers would be installed between each generator and its associated transformer to provide protection and/or synchronization for the generator. These circuit breakers would be installed in a downstream gallery below the tailrace deck (see Fig. 8-15).

The 230 kV metalclad SF6 insulated switchgear would connect the generator transformers to the outgoing 230 kV transmission line, which would be attached to the downstream side of the powerhouse roof. The switchgear, consisting of circuit breakers, disconnect switches, ground switches, and bushings would be located on the tailrace deck.

The station electrical service would be provided at 13.8 kV from taps off the isolated phase bus. A standby diesel generator would be installed to permit operation of the control gates if there is loss of electrical power.

(f) Control

The operation of the powerplant would be controlled from the local control centre and the system control centre on Burnaby Mountain.

(g) Water Supply System

Because of the low operating head at Keenleyside, a pumped water supply system would have to be provided for fire protection, turbine and generator cooling, and domestic water. For this purpose, a raw water pump room would be provided below the service bay.

(h) Design Guidelines

Guidelines adopted for preliminary design are given in Appendix A. They cover the load cases, water levels, mass of materials and uplift conditions to be used for stability analysis. These guidelines are consistent with the design criteria used for other projects designed by B.C. Hydro.

SECTION 9.0 - CONSTRUCTION

9.1 CONSTRUCTION SCHEDULE

The proposed construction schedule for the three 70 MW Kaplan unit powerplant is shown on Fig. 9-1.

The schedule provides for the following in-service dates, as outlined in B.C. Hydro's 1983 Electric System Plan:

Unit 1	August 1992
Unit 2	December 1992
Unit 3	August 1993

The overall construction period, from award of the first contract, in September 1986, to the August 1992 in-service date for Unit 1, would be 6 years.

Final design would proceed shortly after receipt of project approval. It is assumed that this approval would be received by January 1985.

Award of the first civil contract, for cofferdams and excavation, would be necessary in September 1986 to take advantage of the annual low reservoir period, in early 1987, for construction of the upstream cofferdam. This would allow the cofferdams to be completed and the excavation to be well advanced prior to tendering the main civil contract. Some detailed excavation would be carried out under the main civil contract.

Because of the extensive model testing required for the large diameter, low head Kaplan units and the desirability of having finalized powerhouse water passage dimensions prior to tendering the main civil contract, there should be a minimum of 11 months between the award of the turbine contract and the tender issue for the main civil contract. However, as there is a possibility that tenderers for the turbine and generator contracts may submit an acceptable alternative proposal for horizontal axis units, the turbine and generator tenders have been scheduled earlier, so that tenders would close in July 1986, 1 month before the close of tenders for cofferdams and excavation. This would allow turbine type and approximate powerhouse dimensions to be confirmed prior to close of tenders for cofferdams and excavation. [If an alternative proposal for horizontal axis units were to be accepted, it may still be possible to meet the first in-service date scheduled for the Kaplan units. An alternative design for horizontal axis units and the arrangement modifications necessary to provide acceptable approach flow conditions will be investigated further during the initial stages of final design.]

The turbine and generator contracts are scheduled to be awarded at the same time as the first civil contract, in September 1986. To meet this award date it would be neccessary to issue the tenders for the turbines and generators in March 1986.

The main civil contract, for construction of the powerplant and completion work, would be awarded in August 1988, allowing 44 months from award of contract to Unit 1 ready for test.

Installation of the turbine for Unit 1 would begin in October 1990, with Units 2 and 3 following at 6 month intervals. 18 months has been allowed for installation of the turbine and generator in each unit with an additional 2 months for testing and commissioning.

The start of wet testing of Units 1 and 3 would be deferred by up to 2 months from the time that installation of each unit is complete. This is due to the annual low reservoir period, during which the reservoir is below the minimum operating level for the units. Therefore, the in-service date for Unit 1 would be 48 months from award of the main civil contract. This schedule will permit Unit 2 to be in-service by December 1992 so that some generation could be achieved on this unit before the annual low reservoir period in 1993.

9.2 CONSTRUCTION SEQUENCE

The construction sequence can be divided into five main phases, as shown on Fig. 9-2 and as follows:

Phase A: Site Preparation and Cofferdams: November 1986 to May 1987 (6 months)

Construction would begin in November 1986 with the construction camp and offices. In January 1987 work would proceed on the upstream cofferdam. While the Arrow Lakes Reservoir was drawn down early in the year some of the existing sand and gravel fill overlying the till blanket would be removed allowing connection of the impervious core of the cofferdam with the existing till blanket.

Excavation and fill for the downstream earth-rockfill cofferdam would start in February 1987.

A temporary bypass road would be constructed to reroute highway traffic above the existing highway. Work would proceed on the main excavation while the cofferdams were being constructed, but would be restricted to material above El. 442 m until the upstream cofferdam was tested for seepage under full reservoir head. This testing is considered necessary because the upstream cofferdam would function essentially as the main dam for 5 years.

Phase B: Excavation and Completion of Cofferdams: May 1987 to April 1989. (23 months)

After testing of the upstream cofferdam, excavation would proceed below El. 442, but would be restricted to material above tailwater levels until the downstream cofferdam was complete. The downstream earth-rockfill cofferdam would be completed by the end of February 1988.

Most excavation would be completed during 1988, except for the powerhouse area where final rock excavation would be completed by April 1989.

Phase C: Powerplant Construction April 1989 to January 1992 (33 months)

Concrete placement would begin in April 1989. Erection of the superstructure and installation of gates, cranes and trashracks, which would follow completion of first stage structural concrete in each area, would be completed during this phase.

Installation of the turbine for Unit 1 would begin in October 1990, with Units 2 and 3 following at 6 month intervals.

The concrete gravity dams, highway relocation, access roads and the approach channel blanket, except for the blanket connection below the upstream cofferdam, would be completed during this phase.

Phase D: Cofferdam Removal and Powerplant Completion January 1992 to April 1993 (15 months)

The upstream cofferdam would be removed during the annual low reservoir period in 1992. The downstream portion of the cofferdam would be excavated to allow completion of the till blanket between the intake channel and the existing till banket. When the reservoir approached minimum level, about mid-March 1992, cofferdam removal would be completed.

The downstream cofferdam would be breached in February 1992 and excavation and riprap placement for the weir would be completed by late May 1992, prior to wet testing of Unit 1.

Unit 1 wet testing would proceed early in June 1992, when the reservoir reached El. 430.

Installation of all remaining powerhouse equipment would be completed during this phase.

Phase E: Remove Downstream Weir, Last Unit In-Service: April to August 1993 (4 months)

Impounding of the proposed Murphy Creek reservoir would commence in the spring of 1993. At this time the weir would be excavated to the final lines of the tailrace.

Testing and commissioning of the last unit (Unit 3) would be completed by August 1993.

9.3 MAJOR CONTRACTS AND WORK QUANTITIES

For the schedule shown in Fig. 9-1, the construction work would be divided into four major contracts:

1. A contract (KN-1) for site preparation, cofferdams and excavation for the powerplant and highway relocation.

2. A contract (KN-2) for supply and installation of the turbines.

3. A contract (KN-3) for supply and installation of the generators.

4. A contract (KN-4) for the powerplant main civil works including completion of excavation, construction of the powerhouse, intakes and gravity dam sections, installation of gates and cranes and auxiliary mechanical and electrical equipment, completion work and site restoration.

Estimates of major quantities for the civil work are as follows:

Contract KN-1 (Phase A and B of Construction Sequence):

Cofferdams	- excavation	220 000 m^3
	- fill	320 000 m^3
Excavation	- overburden	1 530 000 m^3
	- rock	450 000 m^3

Contract KN-4 (Phase C, D and E of Construction Sequence):

Concrete		160 000 m^3
Fill	- blanket and rip-rap	100 000 m^3
Excavation	- cofferdam removal	200 000 m^3

9.4 CONSTRUCTION METHODS AND PLANT

The methods and equipment employed for construction of the generating facilities would be of the Contractor's choice. However, for planning purposes, certain assumptions have been made as to the construction methods.

(a) Excavation, Fill and Construction Material Borrow Areas

Construction costs for fill materials, except the till required for cofferdams and blanket, are based on reusing granular and rockfill materials from the excavations.

About 150 000 m^3 of glacial till would be required: about 70 000 m^3 for extension of the impervious blanket through the approach channel for the powerplant along with about 80 000 m^3 of till for the cofferdams. This material would be obtained from Area 9, the Balfour till pit. An existing haul road 5.5 km long provides access to the till pit from the Robson-Broadwater Highway from a turnoff located 1.5 km upstream of the dam.

A rock quarry, Area 8, would be used in the event that sufficient volume of suitable rock spoil is not available from the required excavation.

It is expected that all other fill materials would be obtained from the excavation for the powerplant and highway relocation (Area 3).

The total amount of processed concrete aggregate required would be approximately 200 000 m^3. Although Area 6 contains an estimated 260 000 m^3 of unprocessed material suitable for concrete aggregate, it is expected that this material will have to be supplemented by additional quantities from Area 4 (ramp) or Area 3 (powerhouse excavation).

(b) Spoil Areas

Surplus excavation materials would be disposed of in spoil areas located on the left bank of the reservoir within 3 km of the project site.

Seven potential spoil areas are shown on Fig. 9-3. They comprise two areas (Areas 11 and 12) above the Robson-Broadwater Highway and five areas (Areas 4, 5, 6, 7 and 10) located below the highway on the left bank of the reservoir.

Areas 11 and 12, above the highway, are old borrow areas that would be refilled to approximately the original topography.

Area 10 is also an old borrow area and lies between the north bank of the reservoir and an island some 80 m offshore (at full reservoir). The remaining four areas would be developed by constructing dykes to retain the spoil. As far as possible, these dykes would be constructed in the dry when the Arrow Lakes Reservoir is drawn down to lower levels for annual flood storage. The dykes would be located at about the El. 430 contour (well above the mean minimum reservoir level) and would be constructed to about El. 442.0 (above maximum reservoir levels). Granular and rockfill protection would be placed on the face of the dykes to prevent erosion.

The spoil material would be placed behind the dykes and would slope upward at a fairly flat gradient from the dyke crest level to about the level of the existing Robson-Broadwater Highway.

(c) Other Construction Facilities and Plant

It is expected that concrete for the powerplant would be supplied from a batchplant located in Area 13 (see Fig. 9-3). Aggregates for concrete would be processed at the borrow pit in Area 6.

A new B.C. Hydro warehouse and storage area would be constructed in Area No. 14. The two existing warehouses, one in Area 13 and one upstream of Area 4, would be made available for Contractor's facilities or disposal after the contents have been transferred to the new warehouse.

An offloading facility, for project equipment delivered by rail, would be provided in the Castlegar area to permit heavier items of project equipment to be delivered via the left bank.

9.5 CONSTRUCTION CAMP

The offices and single labour camp would be located on the north bank, approximately 0.7 km downstream of the dam (see Areas 1 and 2 on Fig. 9-3). This location would provide good access to all work areas and is on property owned by B.C. Hydro.

The camp facilities would be constructed to accommodate a maximum of about 60 percent of the peak labour force of 560 with the remainder assumed to reside off-site. Initially the camp may be constructed to a smaller size with provisions to expand to the maximum 320 persons as the need arises. As shown on Fig. 9-4, the proposed maximum camp development would include four two-storey, 80-unit bunkhouses, a 350-person dining hall and a recreation hall. Parking would be provided for approximately 200 cars in the immediate vicinity of the camp.

Other facilities would include offices for B.C. Hydro and Columbia Hydro Constructors and a materials testing laboratory at the west end of the campsite. Parking would be provided here for approximately 50 cars.

Domestic water would be supplied from two wells drilled in the camp area. For emergency use, two water reservoirs would be located on the higher levels north of the camp and near the highway.

A sewage treatment plant would be constructed at the east (downstream) end of the campsite. Effluent treatment would conform to the requirements of the B.C. Waste Management Act.

Electric power would be obtained from West Kootenay Power and Light which has a distribution line and 69 kV substation in the immediate area.

9.6 ACCESS ROADS

A portion of the Robson-Broadwater Highway is presently located within the proposed excavation. This portion of highway would be relocated onto a temporary bypass road to maintain access around the site for highway traffic during construction, until the permanent highway relocation is complete. The temporary bypass road may be subject to single lane operation or short closures during some phases of excavation or for maintenance of the bypass road.

Public access across the dam crest would be provided during the construction period by rerouting the existing access road as a single lane over the upstream cofferdam. Because of the narrow crest width and a sharp 90° bend where the cofferdam would abut the north bulkhead, the one-way traffic limitation at the lock would be extended to the west end of the cofferdam. To minimize interference between public and construction traffic, an overpass would be provided in the existing access road near the junction with the Robson-Broadwater Highway (Fig. 3-1).

Prior to removal of the upstream cofferdam, the relocated Robson-Broadwater Highway would be opened to highway traffic and the temporary bypass would be abandoned. The dam crest access road would be routed across the powerplant intakes and would be accessed from the relocated highway.

SECTION 10.0 - PROJECT COST ESTIMATES

10.1 CONSTRUCTION COSTS

The estimate of total construction costs, excluding inflation, is shown in Table 10-1. Costs are shown at October 1982 price levels, except for expenditures incurred in prior years.

Costs are included for land acquistion, royalties, relocation of the existing highway, maintenance of access around the site and over the existing dam crest during construction, mitigation and compensation and study costs.

Corporate overhead and interest during construction are excluded from the total construction cost. Transmission costs also are excluded.

Table 10-2 shows the rate of expenditure by fiscal years during the engineering and construction period and is based on the construction schedule (Fig. 9-1).

The total construction costs of the proposed project arrangement, at October 1982 prices, have been estimated as:

Total construction cost = $313.5 million
Cost of capacity = $1493/kW.

10.2 ESTIMATE OF LABOUR FORCE

Table 10-3 shows the estimated labour force by fiscal years. This is based on the rate of expenditures by fiscal years (Table 10-2) and the construction schedule (Fig. 9-1).

ACKNOWLEDGEMENTS

This report has been prepared by the Hydroelectric Generation Projects Division (HGPD) of B.C. Hydro under the direction of the Manager of Development and Design. The Phase 1 Preliminary Design Studies were conducted, and this report prepared, by HGPD's Keenleyside project team whose designated members included:

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Hydrology	K.J. Ketchum
Hydraulics	P.A. Banks/C.Y. Wu
Estimating and Scheduling	M.G. Castle
Electrical Department	G.R. Nightingale
Generation Services Department	
Drafting	M.O. Jensen
Geotechnical Department	
Group Leader	N.G. Stephenson
Geology	T.E. Little
Soil Mechanics	J.K. Lou
Project Layout	L.C. Cernohorsky L.J. Woznow
Mechanical Department	
Turbines	J.H. Lang/W.E. Cliff
Gates and Cranes	S. Bagaric

This report was reviewed by the HGPD Section Supervisors and Department Managers and by the Keenleyside project team members outside HGPD.

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14. Memorandum from D.G. McFarlane to F.J. Patterson dated 19 March 1982.

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16. Geotechnical Dept., Hydroelectric Generation Projects Division, B.C. Hydro. November 1981. Memorandum on Blanket Modifications for Short Channel Arrangement. Report No. H 1467.

TABLE 6-1

KEENLEYSIDE POWERPLANT PROJECT
COMPARISON OF ALTERNATIVE TURBINE TYPES

	($ Million)[*1]		
	Horizontal Shaft Bulb	Vertical Shaft Kaplan	Difference (%)
1. Total Capital Cost			
a. Total Construction Cost	272.6	265.0	-3
b. Corporate Overhead	24.5	23.9	-2
c. Interest during Construction	18.2	20.2	+11
TOTAL	315.3	309.1	-2
2. Annual Cost[*2]	12.28	12.03	-2
3. Annual Benefits[*2]			
a. Firm Energy	18.19[*3]	18.74	+3
b. Secondary Energy	0.78[*3]	0.81	+3
c. Dependable Capacity	1.26	1.26	-
TOTAL	20.23	20.81	+3
4. Net Annual Benefits	7.95	8.78	+10
5. Present Value-Net Benefits	231.5	255.7	+10

[*1] Costs are at October 1981 price levels. Costs are based on installed capacity of 200 MW for both unit types.

[*2] Annual costs and benefits assessed in accordance with Ref. 14.

[*3] Overall plant efficiency for bulb units estimated to be 3 percent lower.

TABLE 10-1

KEENLEYSIDE POWERPLANT

CONSTRUCTION COST ESTIMATE
($ MILLION)

1.	Land and Rights	2.4
2.	Flowage	4.1
3.	Site Access, Clearing and Restoration	1.3
4.	Cofferdams	9.2
5.	Approach Channel and Blanket	7.0
6.	Tailrace Channel	5.6
7.	Concrete Gravity Dam	3.0
8.	Powerhouse and Intakes	
	- Civil	81.2
	- Mechanical	71.3
	- Electrical	49.7
9.	Construction Services	11.3
	Direct Construction Cost	246.1
10.	Contingencies	30.6
11.	Engineering - Final Design and Construction	30.4
12.	Hearing Expenses	0.6
13.	Construction Insurance and Bonds	2.9
14.	Engineering Studies	2.9
	Total Construction Cost	313.5

Notes:

1. Costs are based on October 1982 prices.

2. Contingencies:
   - 10% on turbines and miscellaneous mechanical equipment.
   - 7 1/2% on all other equipment costs.
   - 12 1/2% on civil costs plus $5 million for improvement of approach flow conditions.

3. Engineering - Final Design and Construction:
   11% on Direct Construction Cost plus contingencies.

TABLE 10-2

KEENLEYSIDE POWERPLANT

ESTIMATE OF CONSTRUCTION EXPENDITURES BY FISCAL YEARS
($ Millions)

	TOTAL CONSTRUCTION COST	Prior to 83/84	FISCAL YEAR										
			83/84	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94
COMMON COSTS	198.2	1.2	1.3	1.4	2.1	8.9	28.2	13.2	59.8	53.1	20.8	5.8	2.4
UNIT 1	38.8							2.1	6.3	12.8	16.9	0.7	
UNIT 2	37.7								5.3	6.5	20.6	5.3	
UNIT 3	38.8								2.1	6.3	12.8	16.9	0.7
TOTAL	313.5	1.2	1.3	1.4	2.1	8.9	28.2	15.3	73.5	78.7	71.1	28.7	3.1
UNIT IN SERVICE												1:AUG 2:DEC	3:AUG

Notes:

1. Costs are based on October 1982 prices.
2. Interest during construction, inflation and corporate overhead are not included.
3. Fiscal Year - 1 April to 31 March.
4. Expenditures based on construction schedule (Fig. 9-1) and on construction cost estimate (Table 10-1).

TABLE 10-3

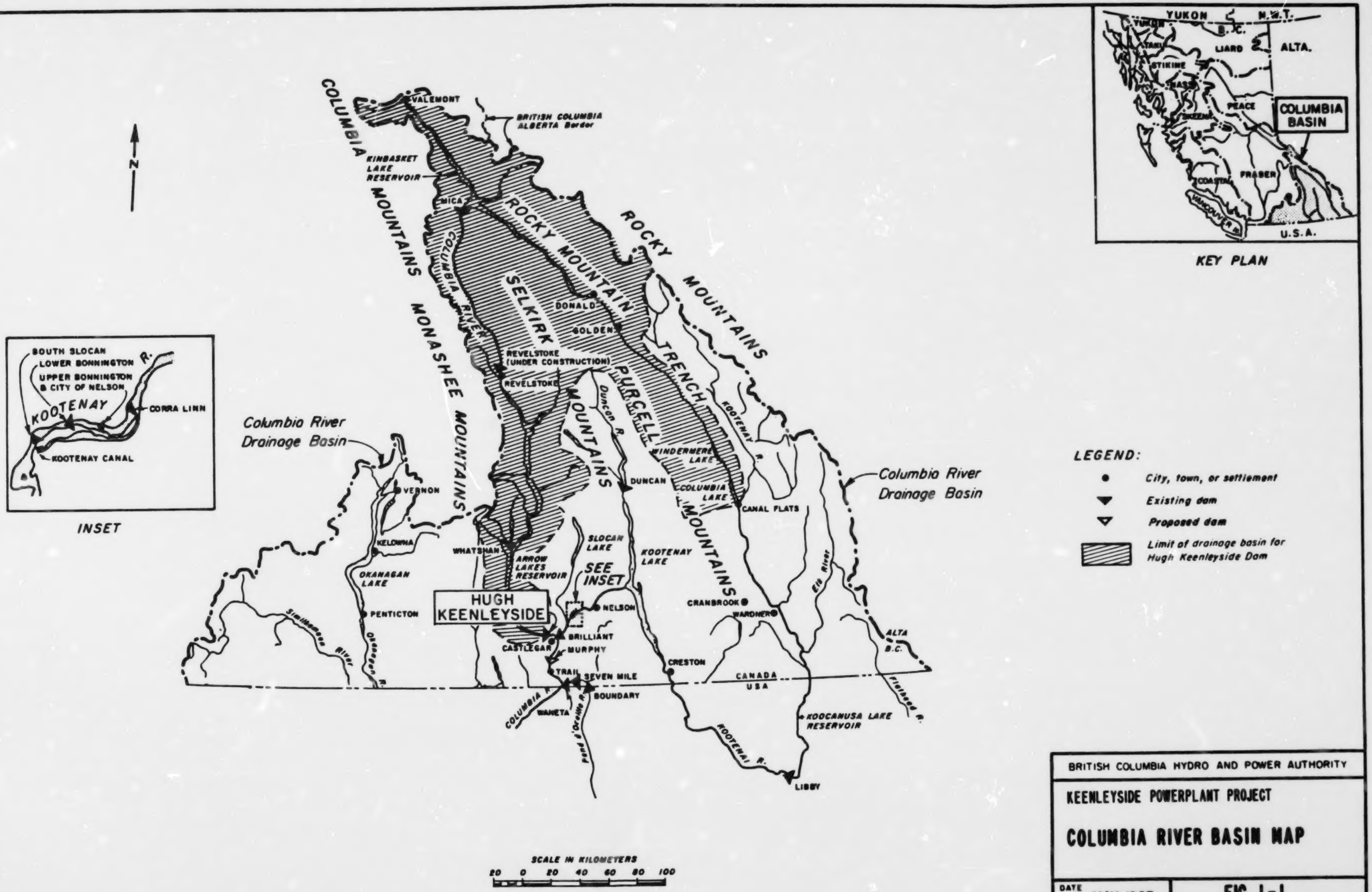
KEENLEYSIDE POWERPLANT

ESTIMATE OF LABOUR FORCE BY FISCAL YEARS

	MAN-YEARS BY FISCAL YEAR								TOTAL MAN-YEARS
	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94	
TRADE UNION									
Tunnel & Rock	12	49	29	106	81	40	22	5	344
IBEW	1	2	7	22	30	51	35	4	152
Carpenters	6	7	9	102	76	40	21	2	263
Machinists	-	-	-	-	10	45	32	2	89
Oper. Engineers	11	53	27	57	49	19	10	5	231
Boilermakers	-	-	-	-	5	11	5	-	21
OTEU	6	21	15	51	57	41	23	4	218
Culinary Workers	1	7	4	19	18	14	9	1	73
Teamsters	4	22	10	30	24	15	10	3	118
Cement Masons	-	-	-	8	11	11	6	1	37
Pipefitters	1	2	3	10	16	18	13	1	64
Iron Workers	4	1	7	30	29	17	12	2	102
Misc. Trades	-	1	1	4	8	7	5	1	27
NON-UNION									
Supervisory	2	9	7	24	19	16	9	2	88
B.C.H. Staff	2	6	6	17	17	15	8	2	73
TOTAL MAN-YEARS	50	180	125	480	450	360	220	35	1900
PEAK MANPOWER	150	230	230	560	540	430	330	130	

Notes:
1. Fiscal year - 1 April to 31 March.
2. Labour force estimate based on estimate of capital expenditures (Table 10-2).

FIGURES



N
COLUMBIA MOUNTAINS
VALEMONT
BRITISH COLUMBIA ALBERTA Border
KINBASKET LAKE RESERVOIR
MICA
COLUMBIA RIVER
ROCKY MOUNTAIN
ROCKY MOUNTAINS
SELKIRK
DONALD
GOLDEN
TRENCH
MONASHEE MOUNTAINS
REVELSTOKE (UNDER CONSTRUCTION)
REVELSTOKE
PURCELL
MOUNTAINS
Duncan R.
KOOTENAY R.
WINDERMERE LAKE
DUNCAN
COLUMBIA LAKE
CANAL FLATS
MOUNTAINS
Columbia River Drainage Basin
Columbia River Drainage Basin
VERNON
KELOWNA
OKANAGAN LAKE
PENTICTON
Similkameen River
Okanagan R.
WHATSHAN
ARROW LAKES RESERVOIR
SLOCAN LAKE
KOOTENAY LAKE
SEE INSET
HUGH KEENLEYSIDE
NELSON
BRILLIANT
CASTLEGAR
MURPHY
TRAIL
SEVEN MILE
BOUNDARY
WANETA
COLUMBIA R.
Pend d'Oreille R.
CRESTON
CRANBROOK
WARDNER
Elk River
ALTA B.C.
CANADA USA
KOOCANUSA LAKE RESERVOIR
KOOTENAI R.
LIBBY
Flathead R.
SOUTH SLOCAN
LOWER BONNINGTON
UPPER BONNINGTON & CITY OF NELSON
KOOTENAY R.
CORRA LINN
KOOTENAY CANAL
INSET
YUKON
N.W.T.
B.C.
ALTA.
YUKON
TAKU
LIARD
STIKINE
NASS
PEACE
SKEENA
COLUMBIA BASIN
COASTAL
FRASER
VANCOUVER IS.
U.S.A.
KEY PLAN
LEGEND:
● City, town, or settlement
▼ Existing dam
▽ Proposed dam
▨ Limit of drainage basin for Hugh Keenleyside Dam
SCALE IN KILOMETERS
20 0 20 40 60 80 100

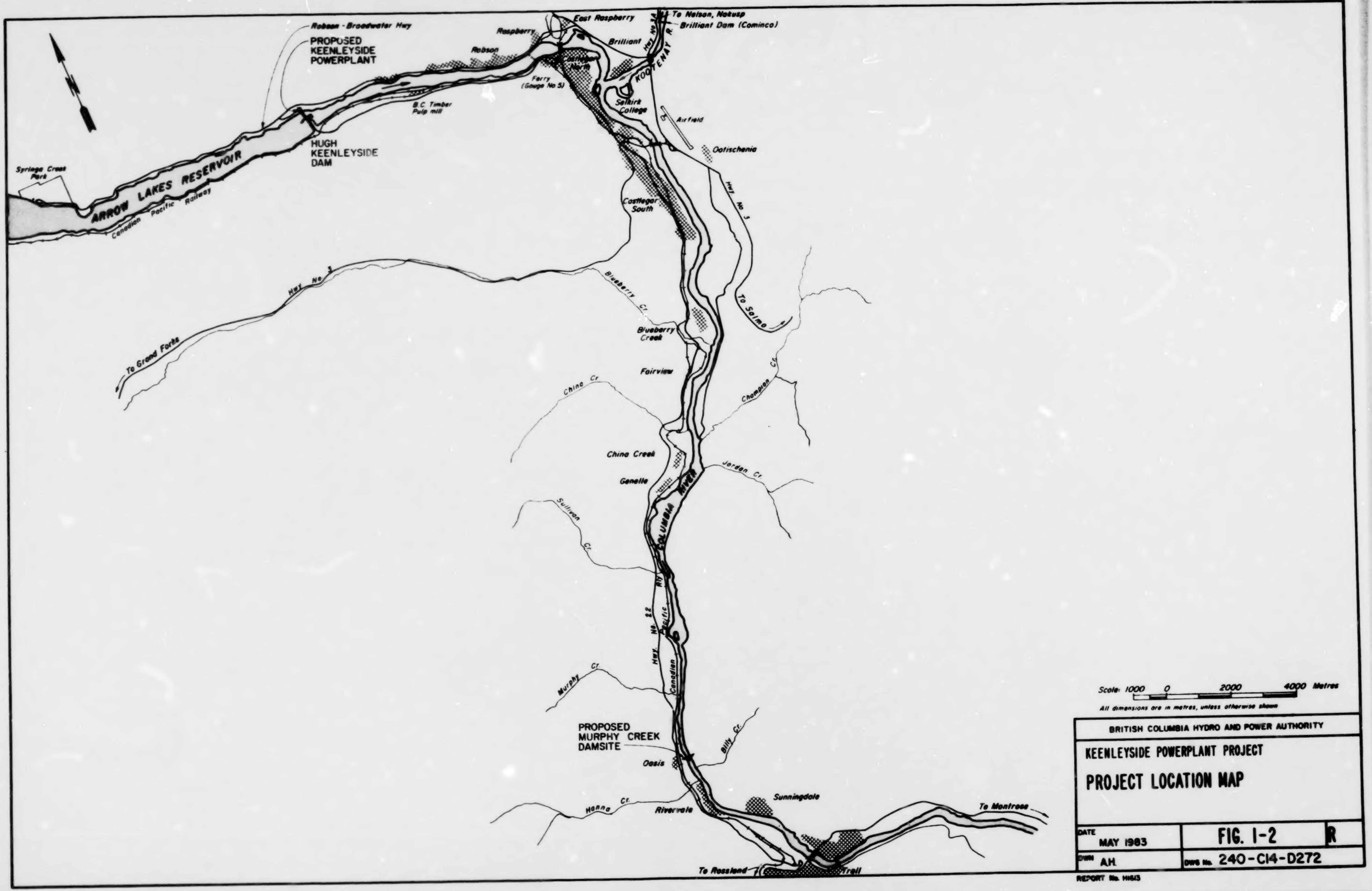
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

COLUMBIA RIVER BASIN MAP

DATE MAY 1983	FIG. 1-1
DWN N.O.	DWG. No. 240-C14-B271

REPORT No. H1613


Robson - Broadwater Hwy
PROPOSED KEENLEYSIDE POWERPLANT
Raspberry
East Raspberry
To Nelson, Nakusp
Brilliant Dam (Cominco)
Robson
Brilliant
Hwy No 3A
KOOTENAY R.
Castlegar North
Ferry (Gauge No 5)
Selkirk College
Airfield
B.C. Timber Pulp mill
HUGH KEENLEYSIDE DAM
Ootischenia
Syringa Creek Park
ARROW LAKES RESERVOIR
Canadian Pacific Railway
Castlegar South
Hwy No 3
Hwy No 3
Blueberry Cr.
To Salmo
To Grand Forks
Blueberry Creek
Fairview
China Cr.
Champion Cr.
China Creek
Genelle
Jordan Cr.
Sullivan Cr.
COLUMBIA RIVER
Hwy No 22
Canadian Pacific Rly
Murphy Cr.
PROPOSED MURPHY CREEK DAMSITE
Billy Cr.
Oasis
Sunningdale
Hanna Cr.
Rivervale
To Montrose
To Rossland
Trail
Scale: 1000 0 2000 4000 Metres
All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

PROJECT LOCATION MAP

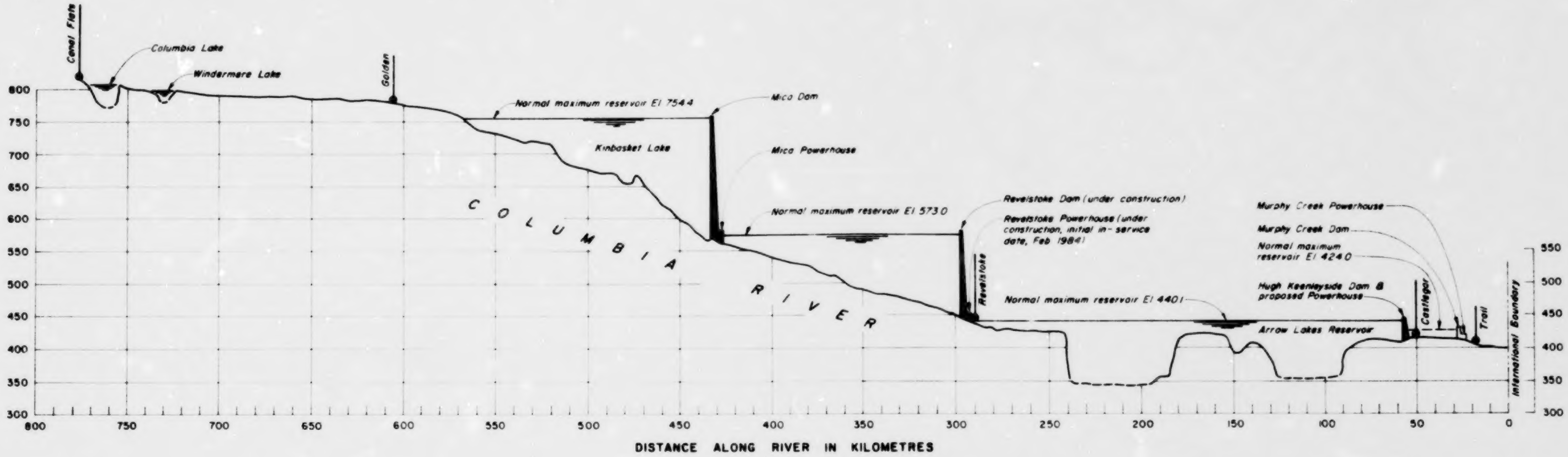
DATE MAY 1983

FIG. 1-2 R

DWN A.H.

DWG No. 240-C14-D272

REPORT No. H1613



RIVER PROFILE

LEGEND

▙	Existing
∟	Proposed
╽	City or town

All dimensions are in metres, unless otherwise shown

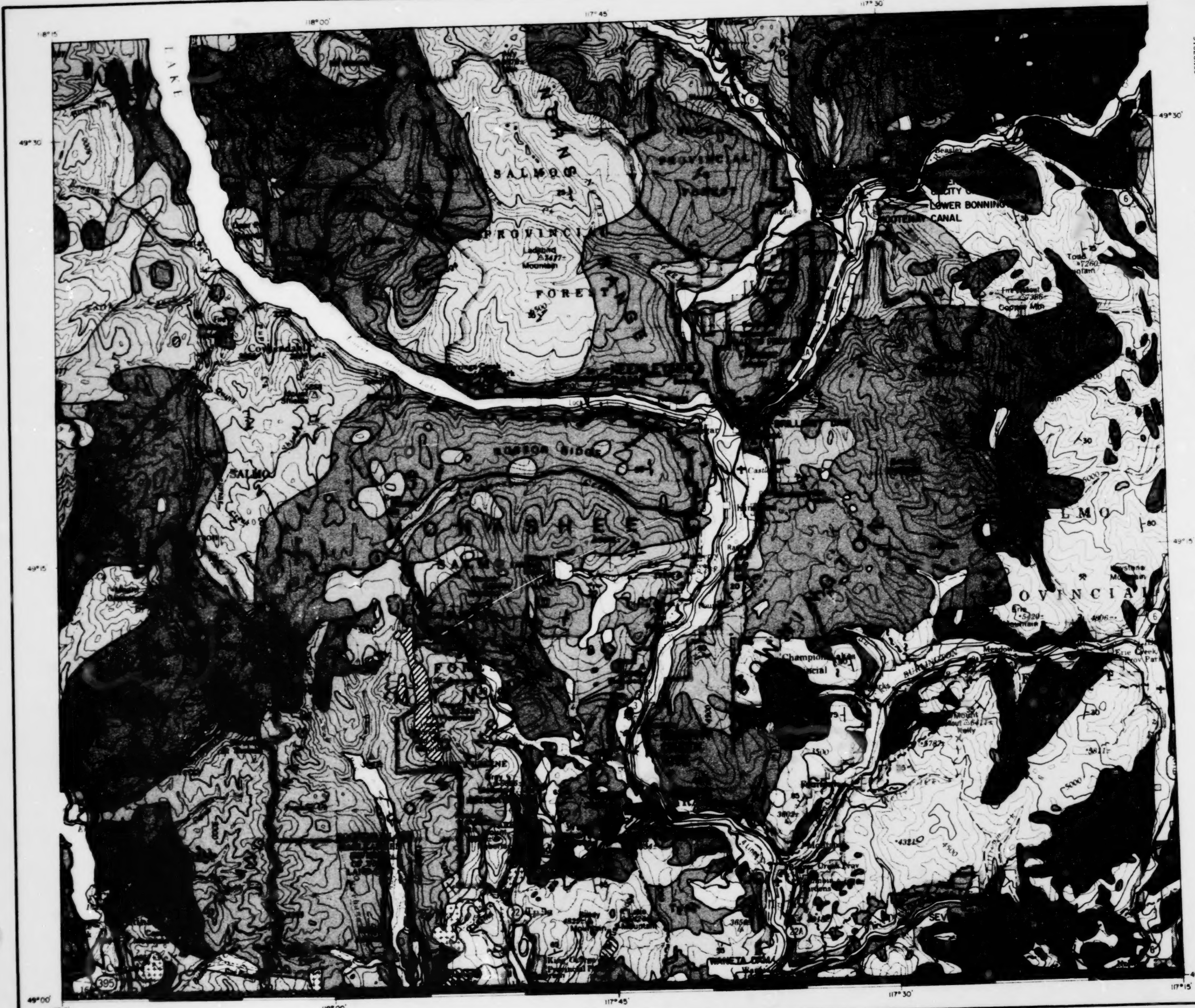
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

COLUMBIA RIVER PROFILE

DATE MAY 1983	FIG. 2-1	R
DWN SM	DWG No. 240-C14-D273	

REPORT No. H1615



118°15'
118°00'
117°45'
117°30'
117°15'
49°30'
49°15'
49°00'
LAKE
SALMO
PROVINCIAL FOREST
LOWER BONNING
KOOTENAY CANAL
ROBSON RIDGE
OVINCIA
Champion Lakes Provincial
Erie Creek Prov Park
WANETA
6
22
22A
395

LEGEND:

CENOZOIC

QUATERNARY

PLEISTOCENE AND RECENT

☐ Till, gravel, sand and silt

TERTIARY

LOWER TERTIARY

░ CORYELL PLUTONIC ROCKS (mostly syenite) and SHEPPARD INTRUSIONS (leucocratic granite)

EOCENE (?)

▨ Agglomerate and lava flows

CRETACEOUS OR EARLY TERTIARY

UPPER CRETACEOUS (?)

▧ SOPHIE MOUNTAIN FORMATION (conglomerate)

LOWER CRETACEOUS (?)

░ VALHALLA INTRUSIONS (granite)

MESOZOIC

JURASSIC OR CRETACEOUS

UPPER JURASSIC OR LOWER CRETACEOUS

■ NELSON PLUTONIC ROCKS (granitic rocks), including ROSSLAND monzonite and minor quartz - feldspar porphyry

⊞ Ultrabasic rocks, serpentinite

JURASSIC

LOWER, MIDDLE AND (?) UPPER JURASSIC

☐ ROSSLAND GROUP (volcanic rocks, siltstone and shale) including HALL FORMATION AND ELISE FORMATION

LOWER JURASSIC AND (?) OLDER

▓ ARCHIBALD FORMATION (argillite & siltstone) and SINEMURIAN BEDS (argillite and quartzite) including minor YMIR GROUP (argillite)

PALAEOZOIC

CARBONIFEROUS

▒ MOUNT ROBERTS FORMATION (slate, limestone and quartzite)

ORDOVICIAN AND CAMBRIAN

▓ ACTIVE, NELWAY, LAIB, RENO AND QUARTZITE RANGE FORMATIONS (argillite, limestone, dolomite and quartzite)

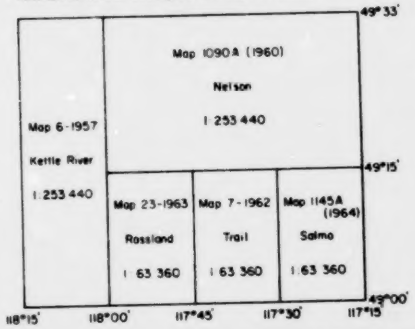
AGE UNKNOWN

░ Mostly gneiss, including some argillite (especially along Pend D'Oreille River)

✕ 60	Strike and Dip of Bedding (Vertical, inclined)
✕ 40	Strike and Dip of Gneissosity (Vertical, inclined)
∼∼	Fault (approximate or assumed)

NOTES:

1. This map is based on the following maps by H.W. Little of the Geological Survey of Canada:



49°33'
Map 1090A (1960)
Nelson
1:253 440
Map 6-1957
Kettle River
1:253 440
49°15'
Map 23-1963
Rossland
1:63 360
Map 7-1962
Trail
1:63 360
Map 1145A (1964)
Salmo
1:63 360
49°00'
118°15'
118°00'
117°45'
117°30'
117°15'

2. Topography is taken from National Topographic System maps 82E and 82F (1973 edition, elevations in feet)

Scale: 2.5 0 2.5 5 7.5 10 Kilometres

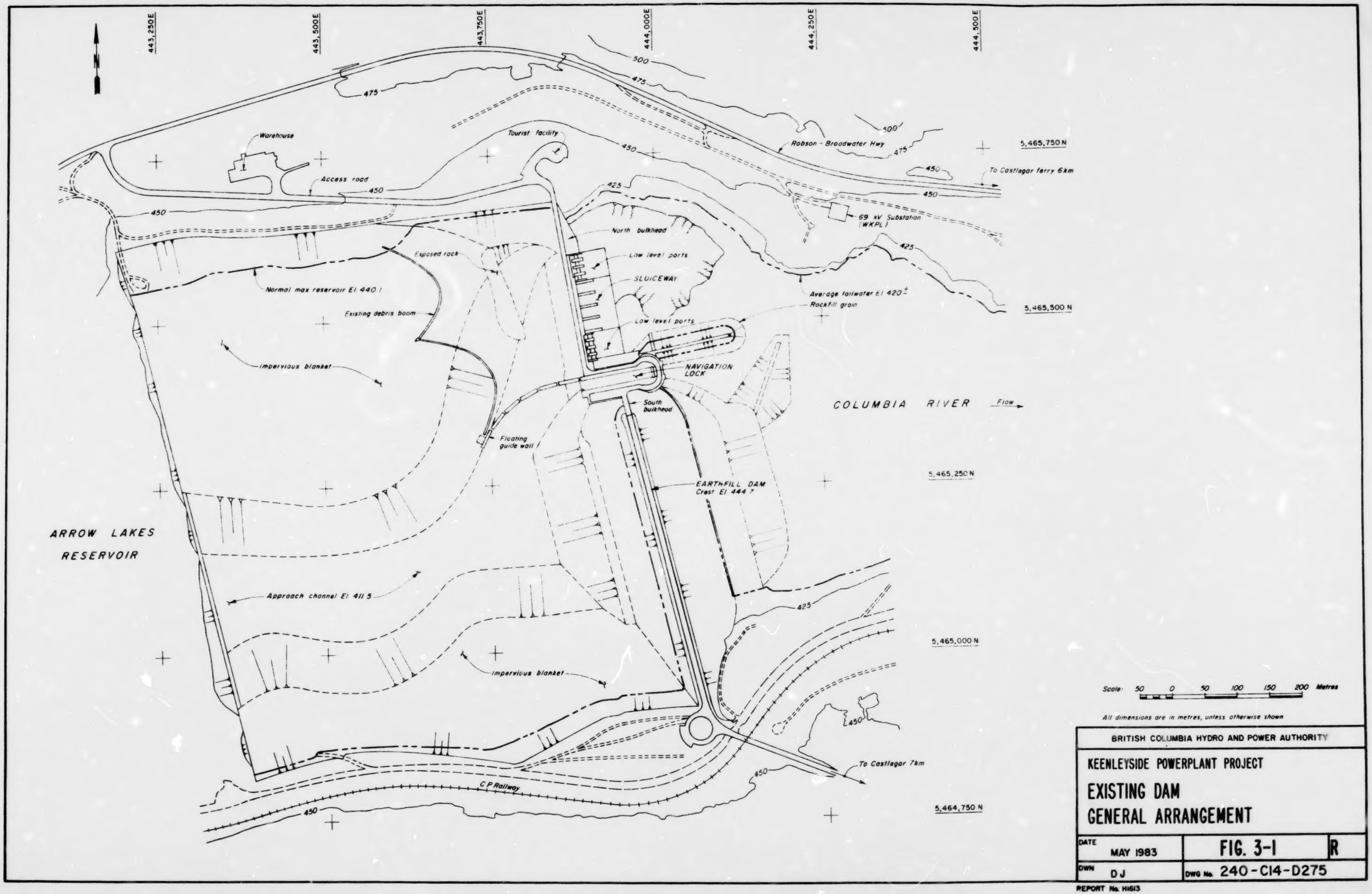
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

REGIONAL GEOLOGY

DATE MAY 1983	FIG. 2-2
DWN GC	DWG No. 240-C14-D274

REPORT No. H1613


N
443,250E
443,500E
443,750E
444,000E
444,250E
444,500E
500
475
450
425
Warehouse
Access road
Tourist facility
Robson - Broadwater Hwy
5,465,750 N
To Castlegar ferry 6 km
69 kV Substation (WKPL)
North bulkhead
Low level ports
SLUICEWAY
Exposed rock
Normal max reservoir El 440.1
Existing debris boom
Average tailwater El 420±
Rockfill groin
5,465,500 N
Low level ports
NAVIGATION LOCK
Impervious blanket
South bulkhead
COLUMBIA RIVER
Flow
Floating guide wall
5,465,250 N
EARTHFILL DAM
Crest El 444.7
ARROW LAKES
RESERVOIR
Approach channel El 411.5
5,465,000 N
Impervious blanket
To Castlegar 7 km
C P Railway
5,464,750 N
Scale: 50 0 50 100 150 200 Metres

All dimensions are in metres, unless otherwise shown

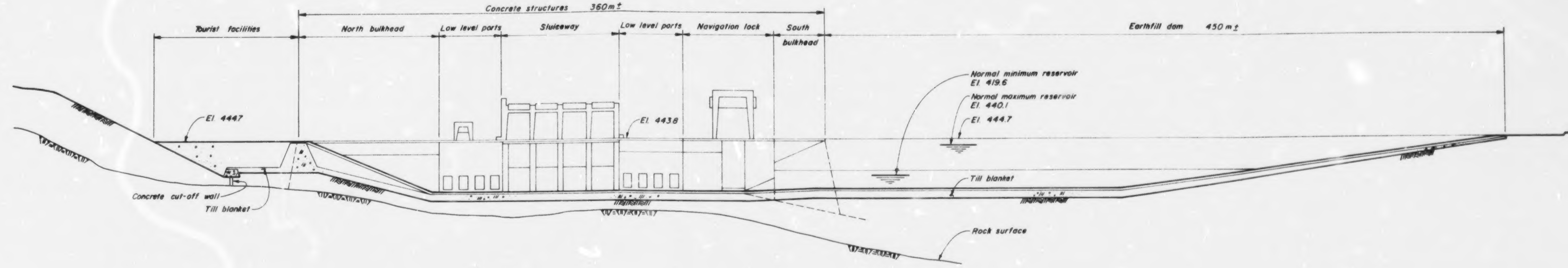
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

EXISTING DAM
GENERAL ARRANGEMENT

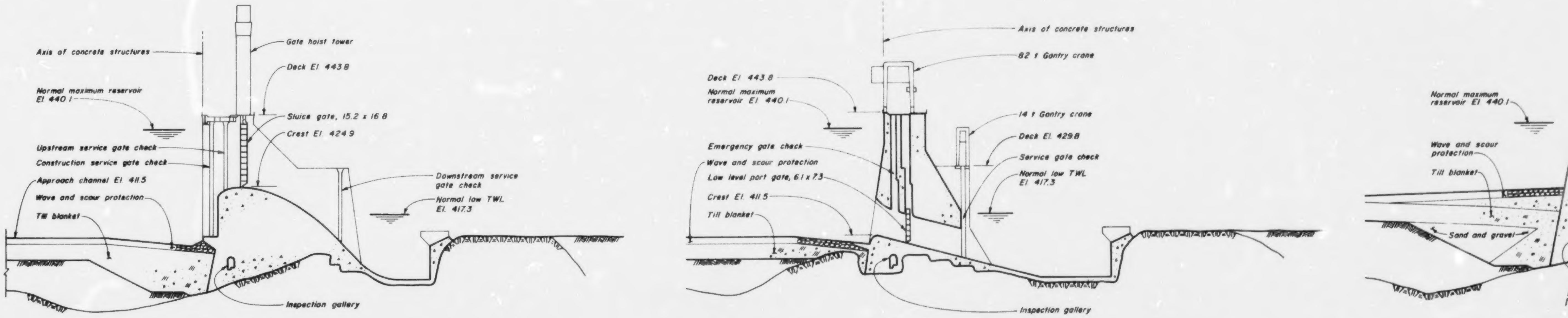
DATE MAY 1983	FIG. 3-1	R
DWN D J	DWG No. 240-C14-D275	

REPORT No. H1613


Concrete structures 360m ±
Tourist facilities
North bulkhead
Low level ports
Sluiceway
Low level ports
Navigation lock
South bulkhead
Earthfill dam 450 m ±
Normal minimum reservoir El. 419.6
Normal maximum reservoir El. 440.1
El. 444.7
El. 444.7
El. 443.8
Till blanket
Concrete cut-off wall
Till blanket
Rock surface

UPSTREAM ELEVATION

Scale A


Axis of concrete structures
Gate hoist tower
Deck El. 443.8
Normal maximum reservoir El. 440.1
Sluice gate, 15.2 x 16.8
Crest El. 424.9
Upstream service gate check
Construction service gate check
Approach channel El. 411.5
Wave and scour protection
Till blanket
Downstream service gate check
Normal low TWL El. 417.3
Inspection gallery
Axis of concrete structures
82 t Gantry crane
Deck El. 443.8
Normal maximum reservoir El. 440.1
14 t Gantry crane
Deck El. 429.8
Service gate check
Emergency gate check
Wave and scour protection
Low level port gate, 6.1 x 7.3
Normal low TWL El. 417.3
Crest El. 411.5
Till blanket
Inspection gallery
Normal maximum reservoir El. 440.1
Wave and scour protection
Till blanket
Sand and gravel

SLUICEWAY

LOW LEVEL PORTS

NORTH BUL

Scal

Sca

All

TYPICAL SECTIONS

Scale B

BRI

KEENLE

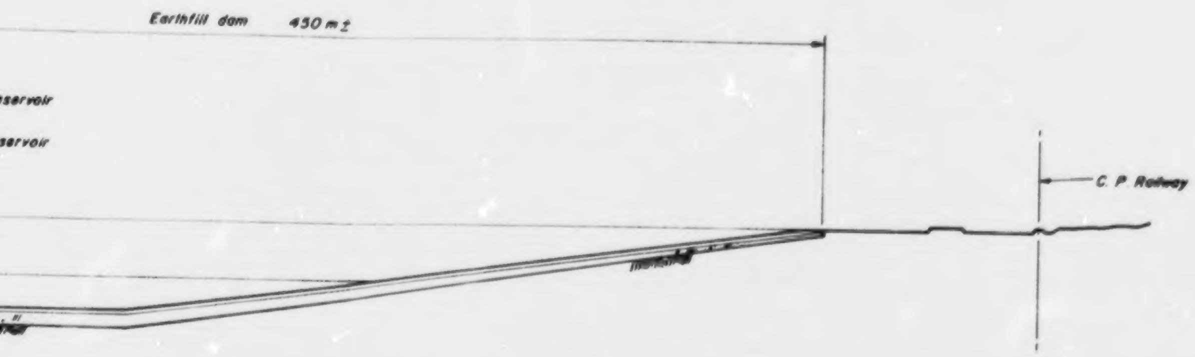
EXIST

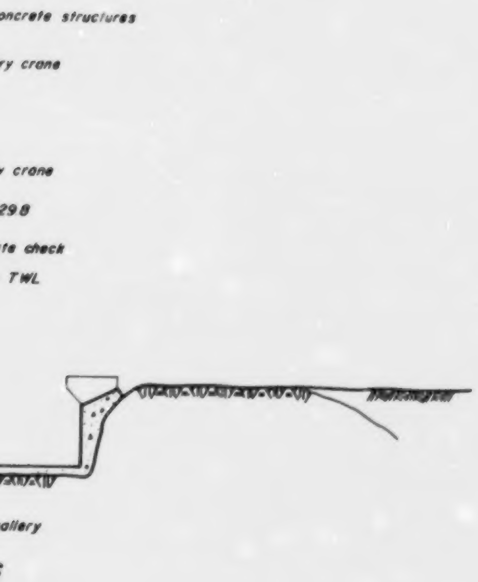
ELEVA

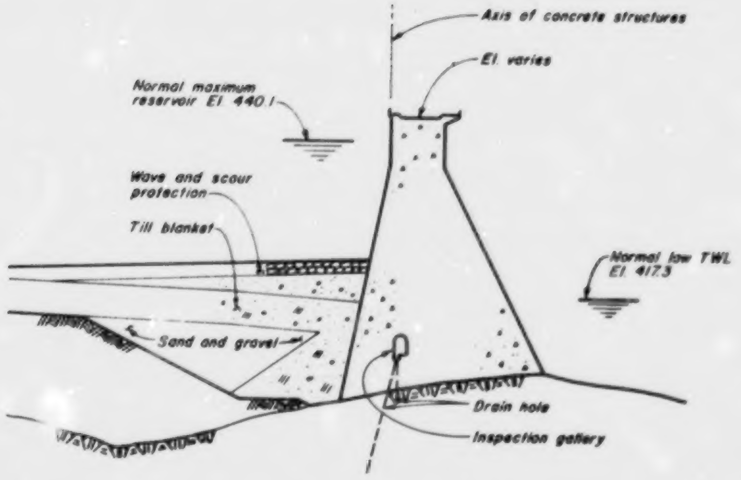
DATE MAY

DWN SM

REPORT No. H


Earthfill dam 450 m ±
servoir
servoir
C. P. Railway


oncrete structures
ry crane
y crane
298
te check
TWL
allery


Axis of concrete structures
El. varies
Normal maximum reservoir El. 440.1
Wave and scour protection
Till blanket
Sand and gravel
Normal low TWL El. 417.3
Drain hole
Inspection gallery

NORTH BULKHEAD

Scale: B 10 0 10 20 30 40 Metres

Scale: A 25 0 25 50 75 100 Metres

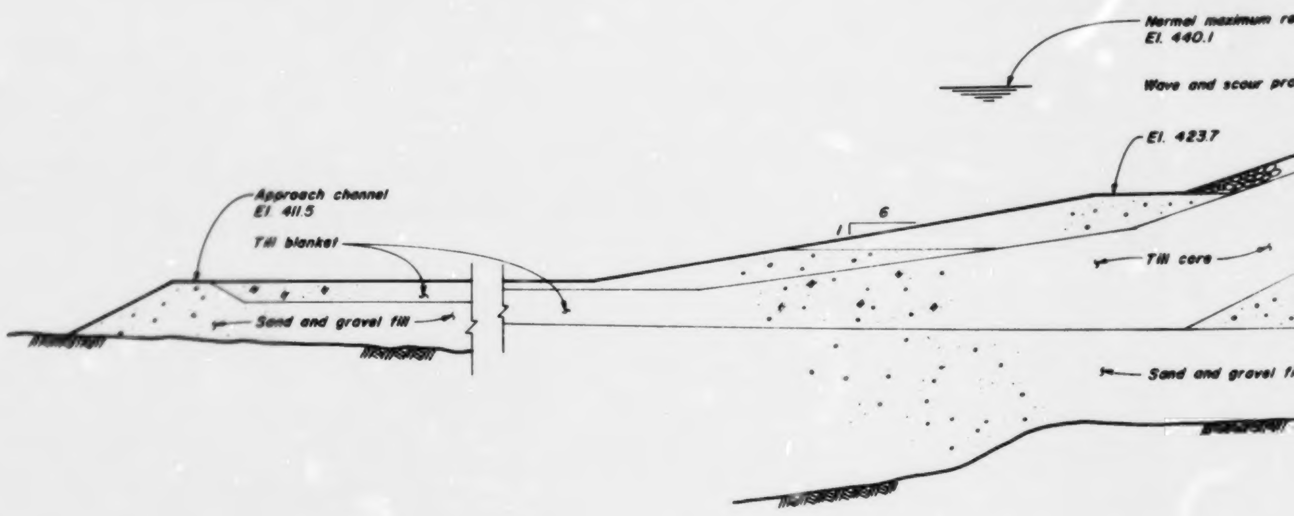
All dimensions are in metres, unless otherwise shown

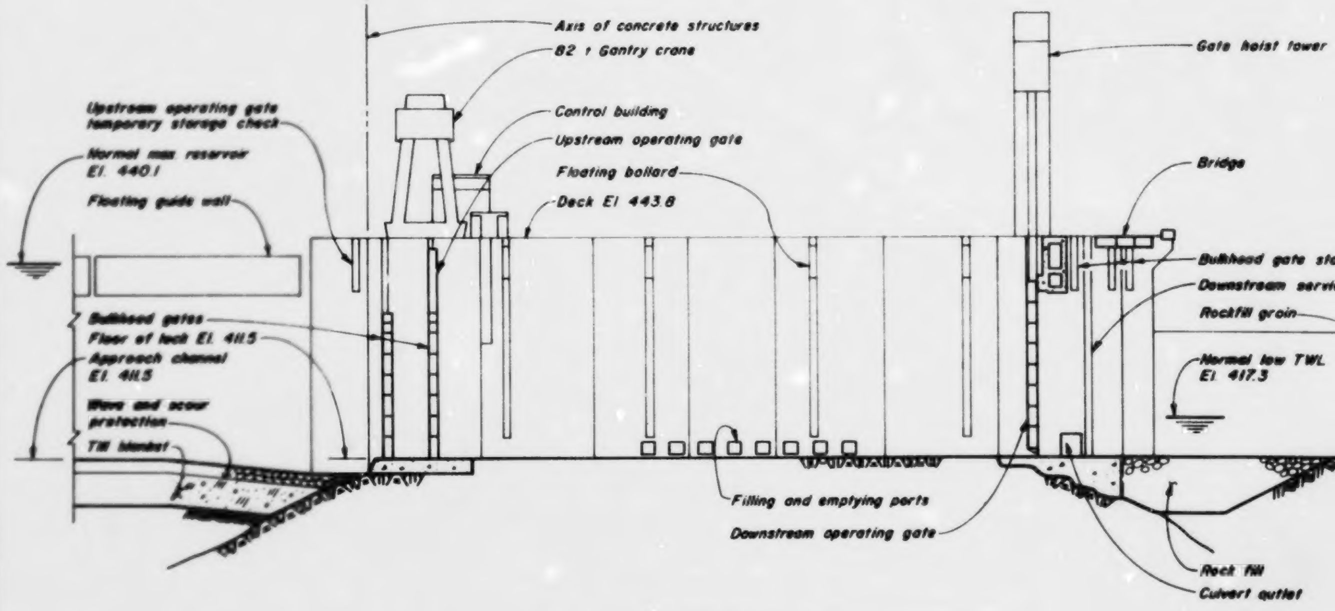
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
EXISTING DAM
ELEVATION & SECTIONS

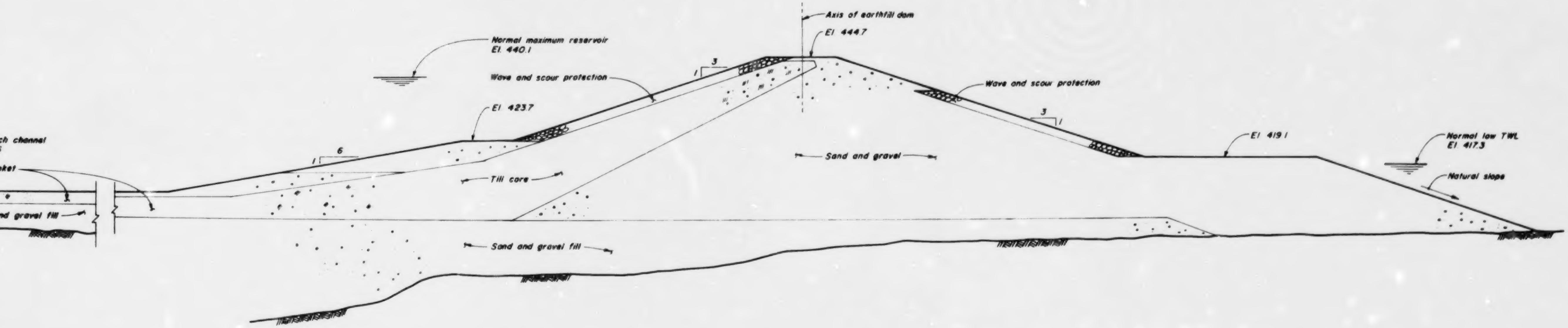
DATE MAY 1983	FIG. 3-2
DWN SM	DWG No. 240-C14-U276

REPORT No. H1613

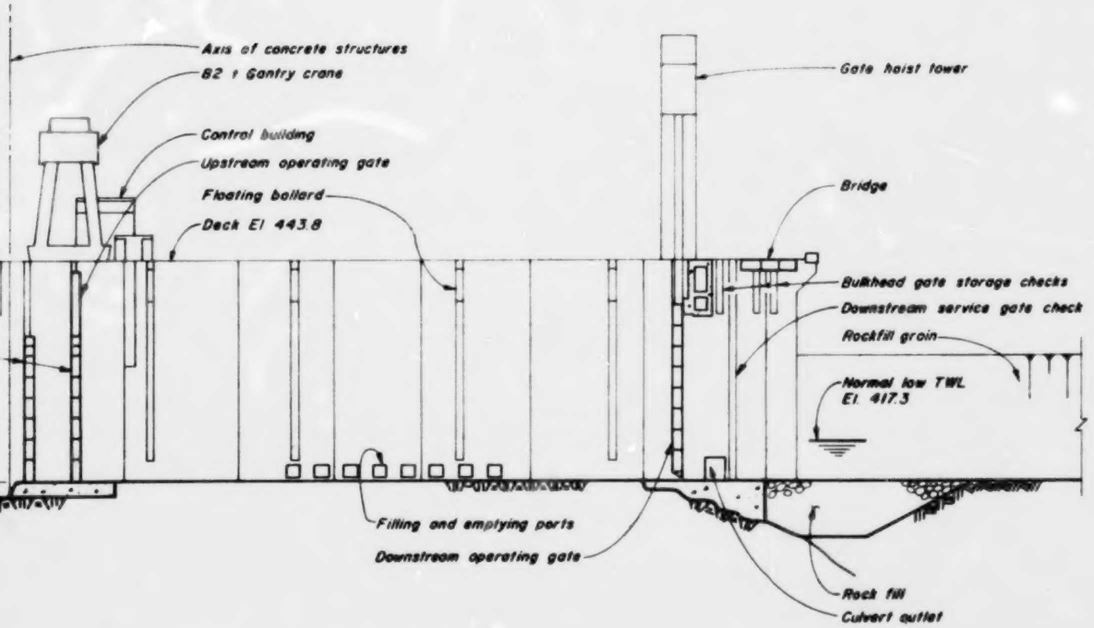

Normal maximum re
El. 440.1
Wave and scour pro
El. 423.7
Approach channel El. 411.5
Till blanket
Sand and gravel fill
1
6
Till core
Sand and gravel fi


Axis of concrete structures
82 t Gantry crane
Control building
Upstream operating gate
Floating bollard
Deck El 443.8
Gate hoist tower
Bridge
Upstream operating gate temporary storage check
Normal max. reservoir El. 440.1
Floating guide wall
Bulkhead gates
Floor of lock El. 411.5
Approach channel El. 411.5
Wave and scour protection
Till blanket
Bulkhead gate sto
Downstream servi
Rockfill groin
Normal low TWL El. 417.3
Filling and emptying ports
Downstream operating gate
Rock fill
Culvert outlet

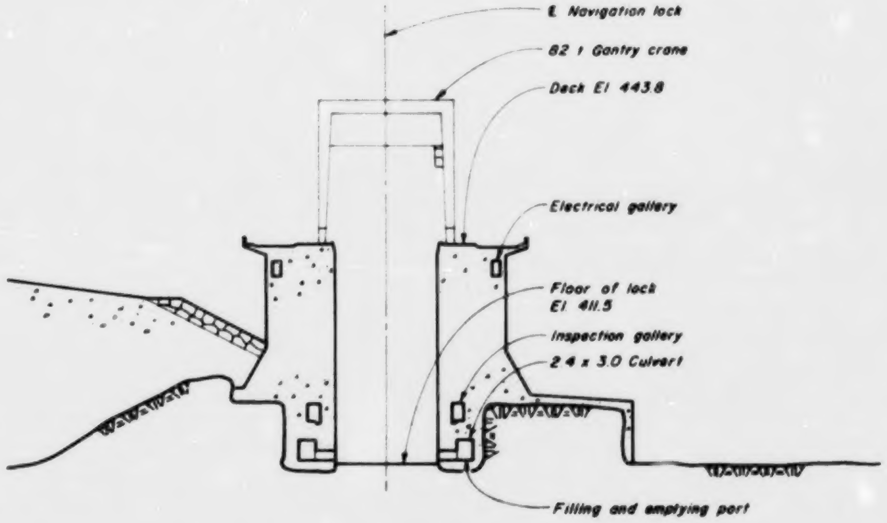
LONGITUDINAL SECTION
NAVIGATION LOCK


Axis of earthfill dam
El 444.7
Normal maximum reservoir
El. 440.1
Wave and scour protection
3
1
El 423.7
ch channel
nket
nd gravel fill
6
1
Till core
Sand and gravel
Wave and scour protection
3
1
El 419.1
Normal low TWL
El 417.3
Natural slope
Sand and gravel fill

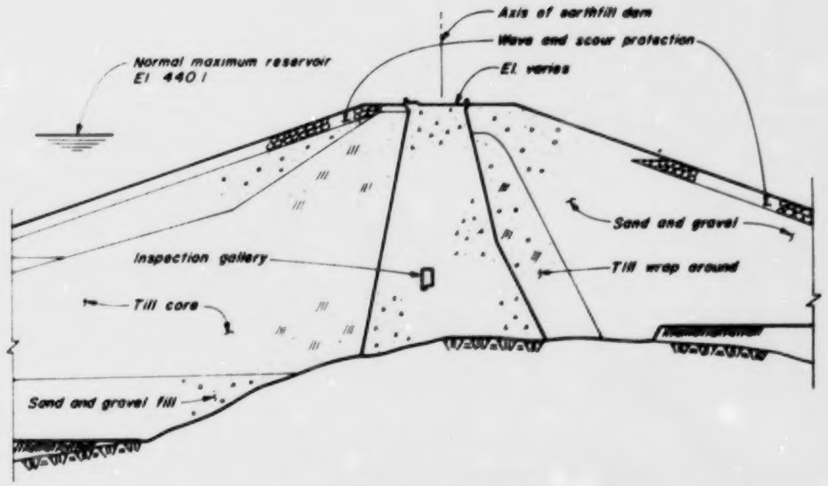
EARTHFILL DAM


Axis of concrete structures
82 t Gantry crane
Control building
Upstream operating gate
Floating bollard
Deck El 443.8
Gate hoist tower
Bridge
Bulkhead gate storage checks
Downstream service gate check
Rockfill groin
Normal low TWL
El. 417.3
Filling and emptying ports
Downstream operating gate
Rock fill
Culvert outlet

LONGITUDINAL SECTION
NAVIGATION LOCK


℄ Navigation lock
82 t Gantry crane
Deck El 443.8
Electrical gallery
Floor of lock
El 411.5
Inspection gallery
2.4 x 3.0 Culvert
Filling and emptying port

TRANSVERSE SECTION
NAVIGATION LOCK


Axis of earthfill dam
Wave and scour protection
El. varies
Normal maximum reservoir
El 440.1
Sand and gravel
Inspection gallery
Till wrap around
Till core
Sand and gravel fill

SOUTH BULKHEAD

Scale: 10 0 10 20 30 40 Metres

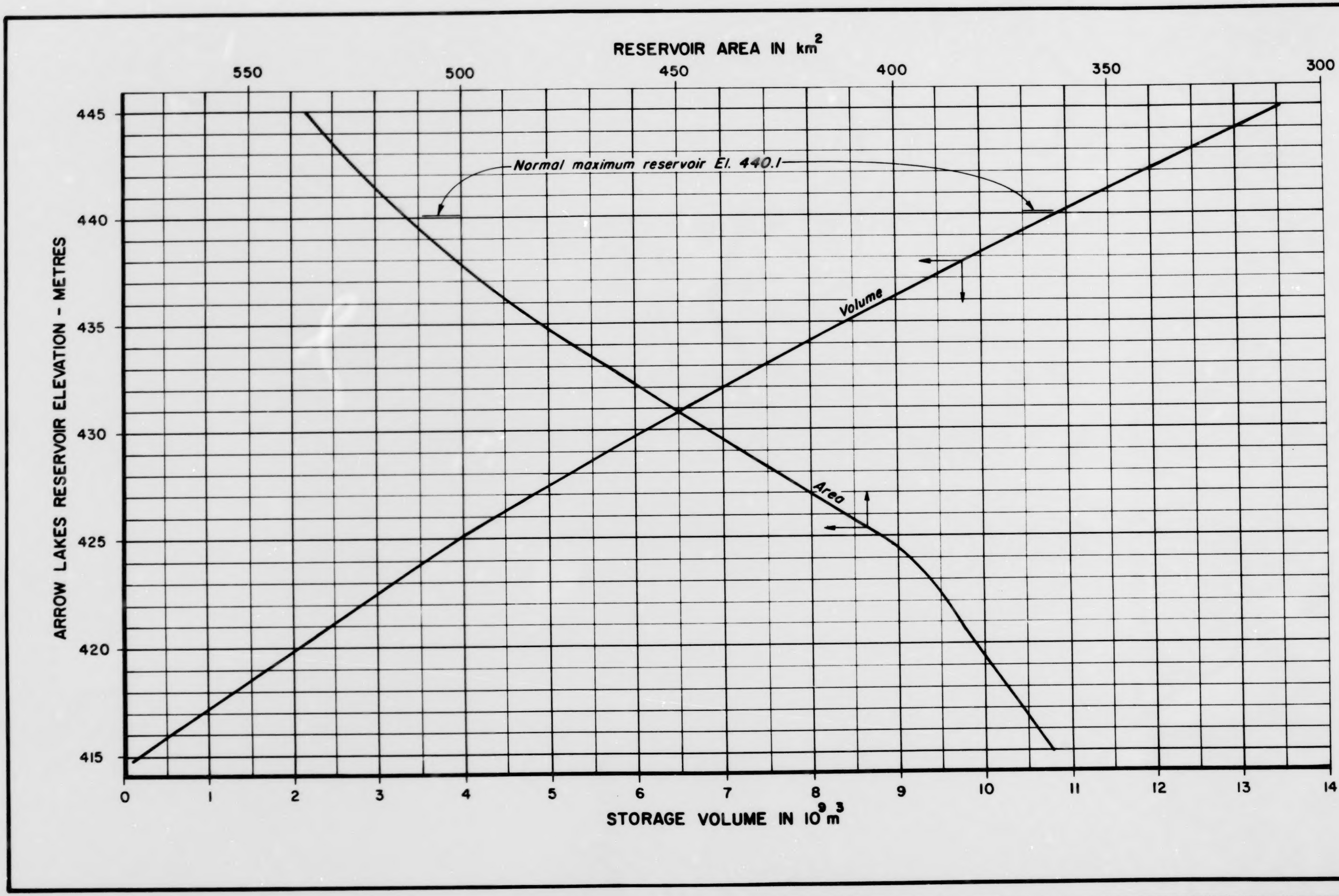
All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
EXISTING DAM
SECTIONS

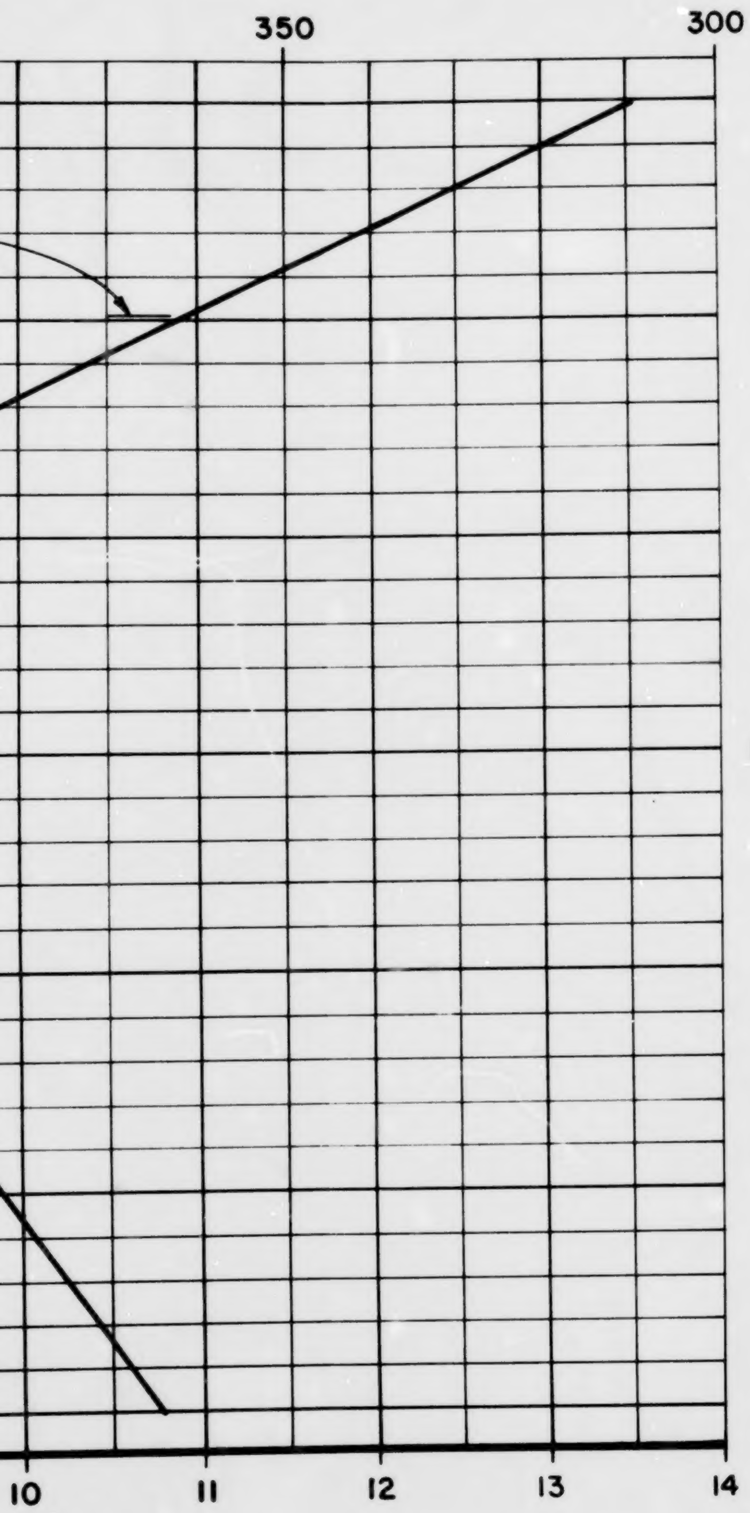
DATE MAY 1983	FIG. 3-3
DWN SM	DWG No. 240-C14-U277

REPORT No. H1643


RESERVOIR AREA IN km^2
550
500
450
400
350
300
445
440
435
430
425
420
415
ARROW LAKES RESERVOIR ELEVATION - METRES
Normal maximum reservoir El. 440.1
Volume
Area
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
STORAGE VOLUME IN 10^9 m^3

NOT

N
A
L



NOTE:

NO ALLOWANCES MADE IN THESE CURVES TO ACCOUNT FOR DIFFERENCES IN UPPER AND LOWER LAKE LEVELS DURING DRAWDOWN CYCLE.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

RESERVOIR AREA AND
VOLUME CURVES

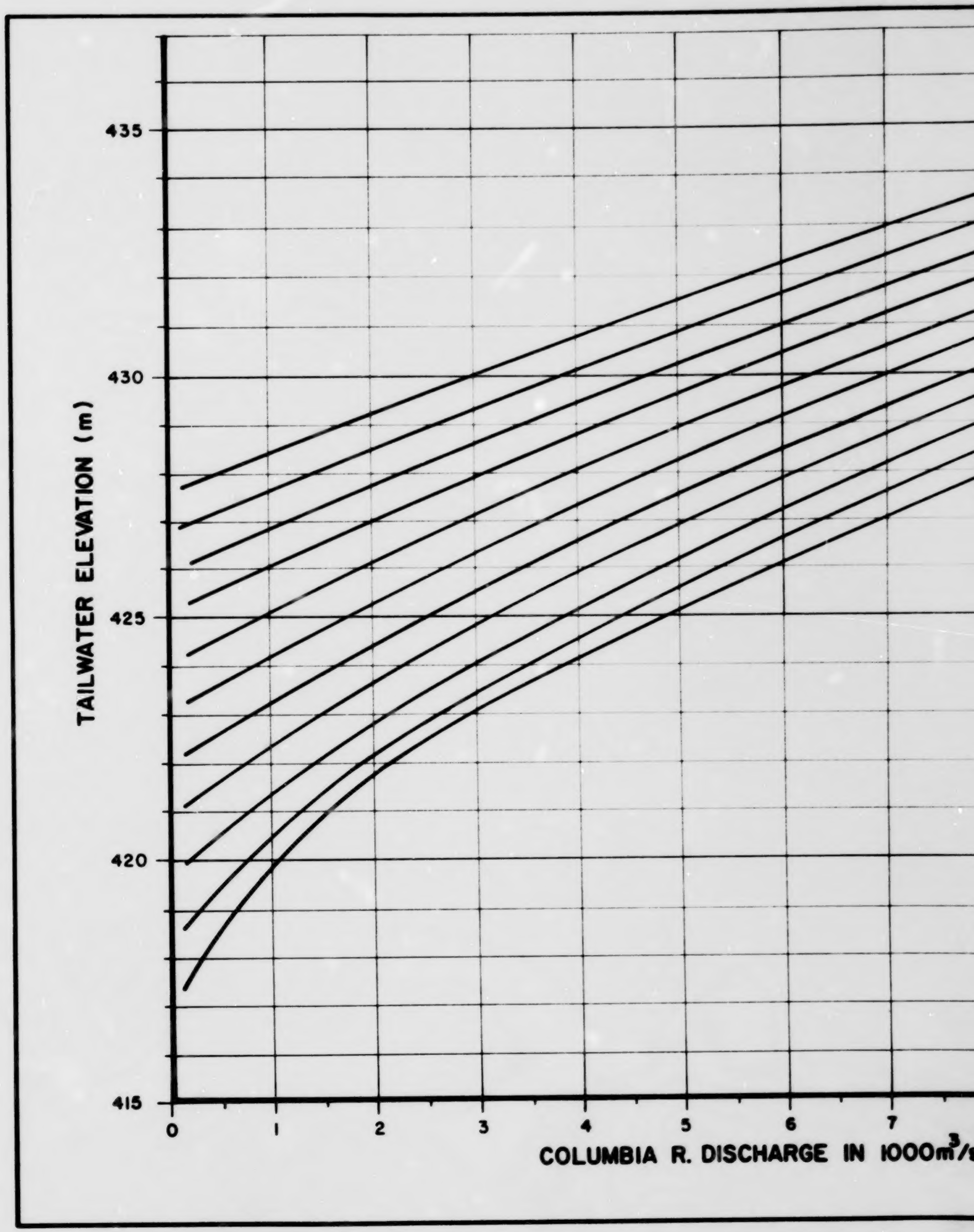
DATE MAY 1983

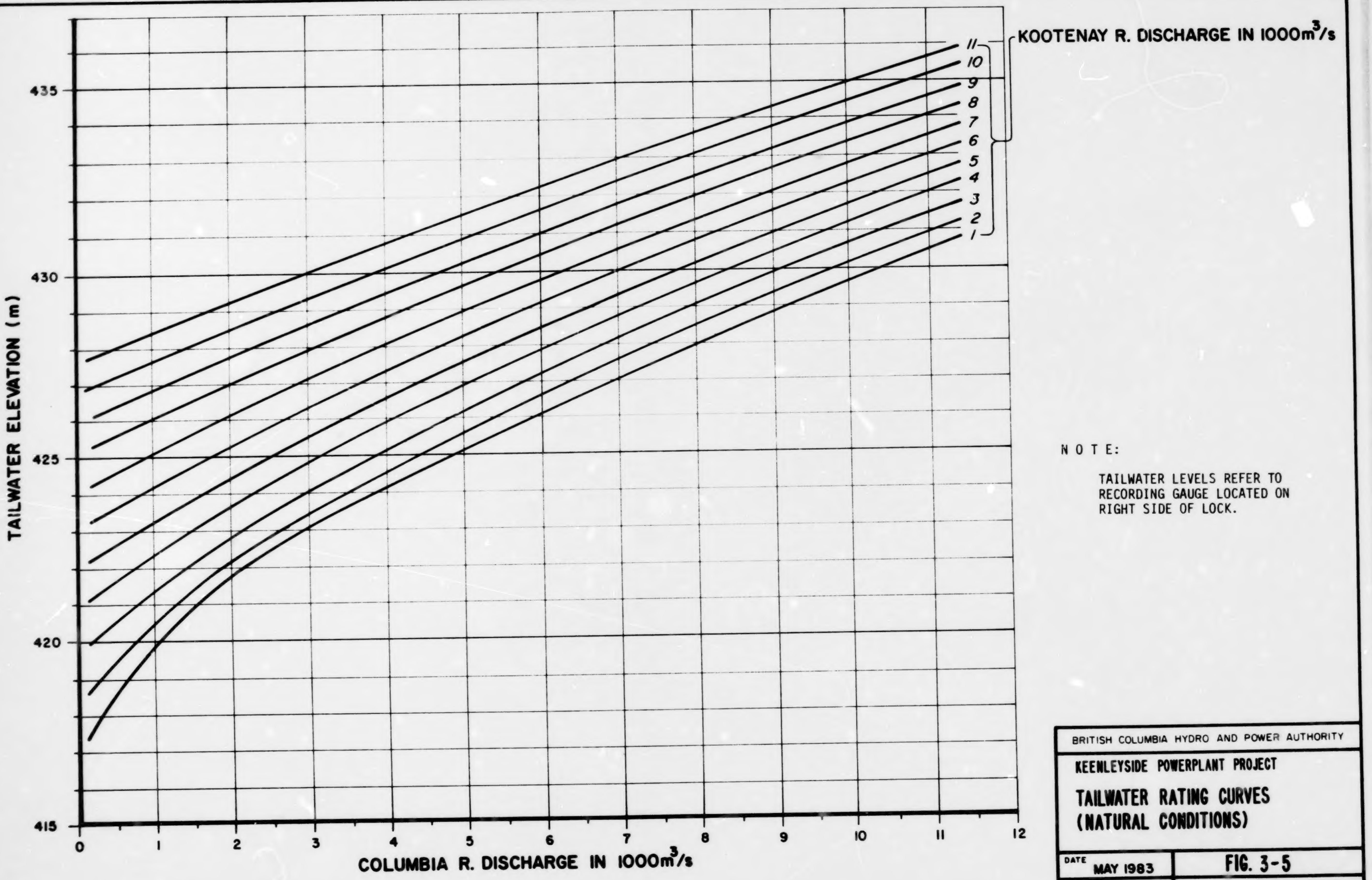
FIG. 3-4

DWN SM

DWG. No. 240-C14-C278

REPORT No. H1613





NOTE:

TAILWATER LEVELS REFER TO
RECORDING GAUGE LOCATED ON
RIGHT SIDE OF LOCK.

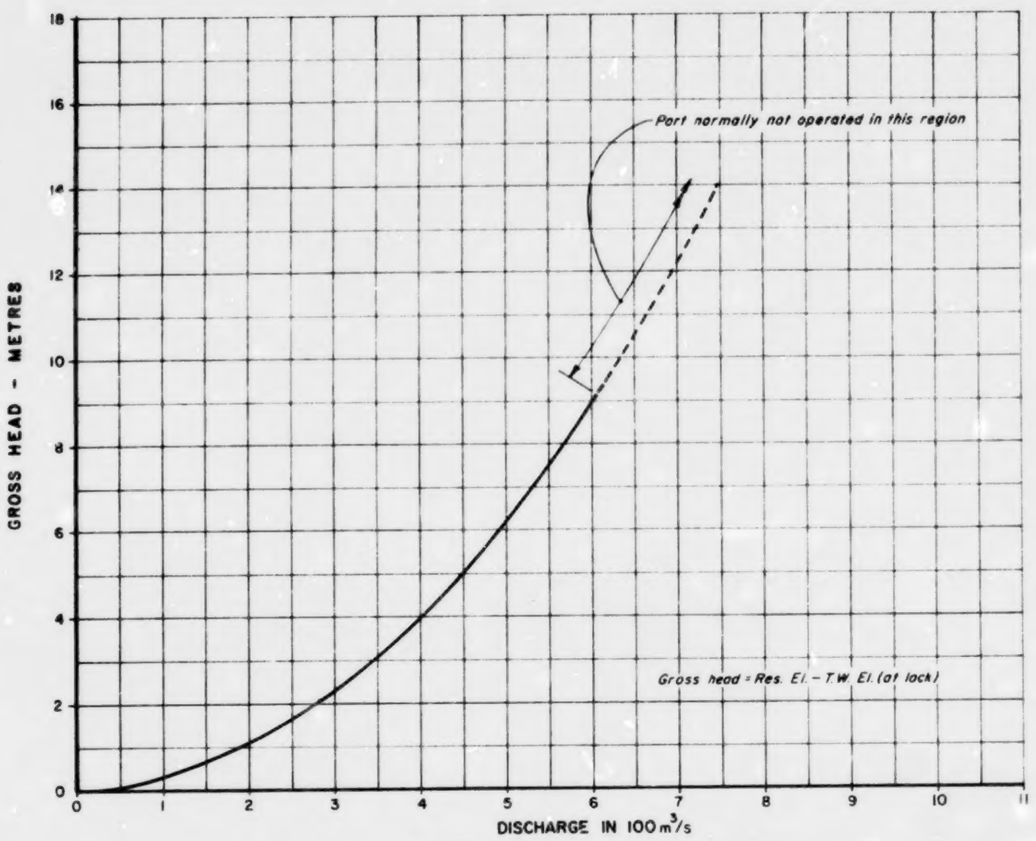
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

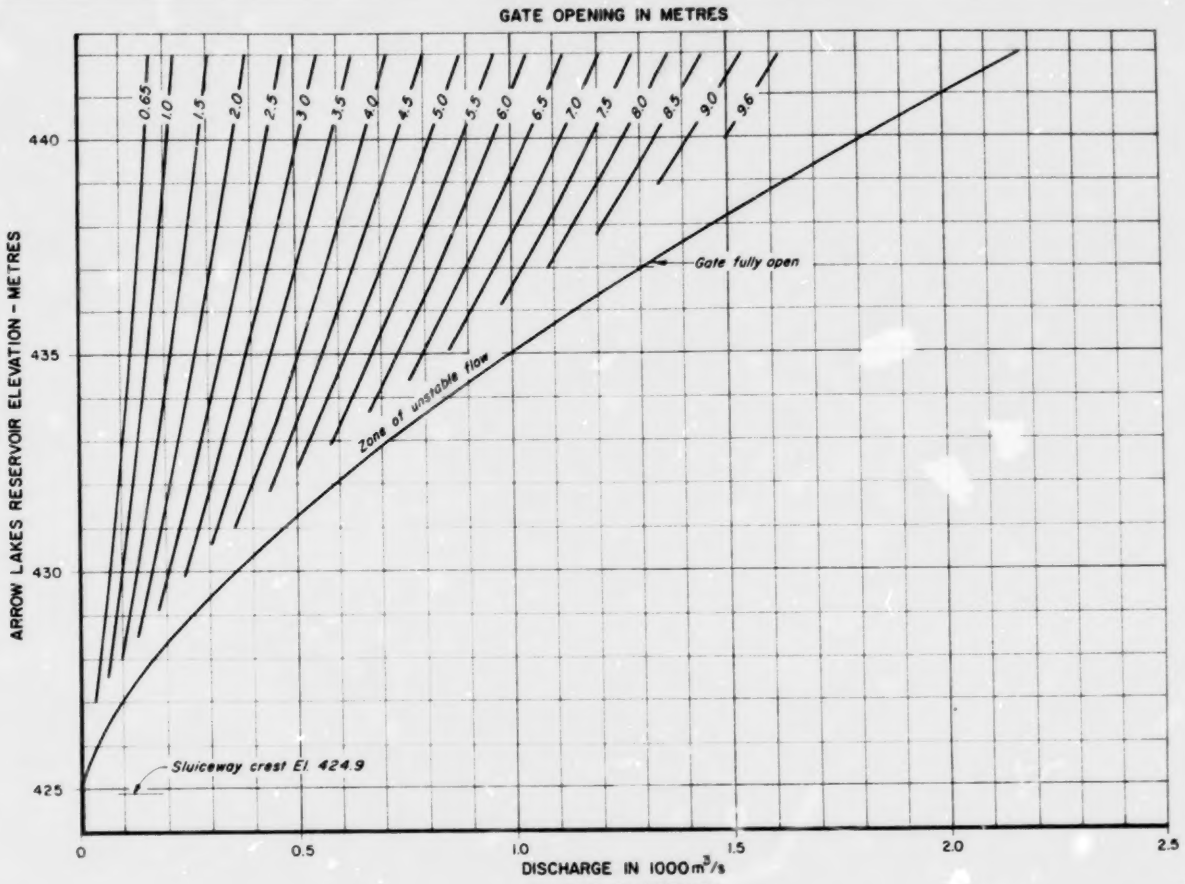
TAILWATER RATING CURVES
(NATURAL CONDITIONS)

DATE MAY 1983	FIG. 3-5
DWN SM	DWG. No 240-C14-B279

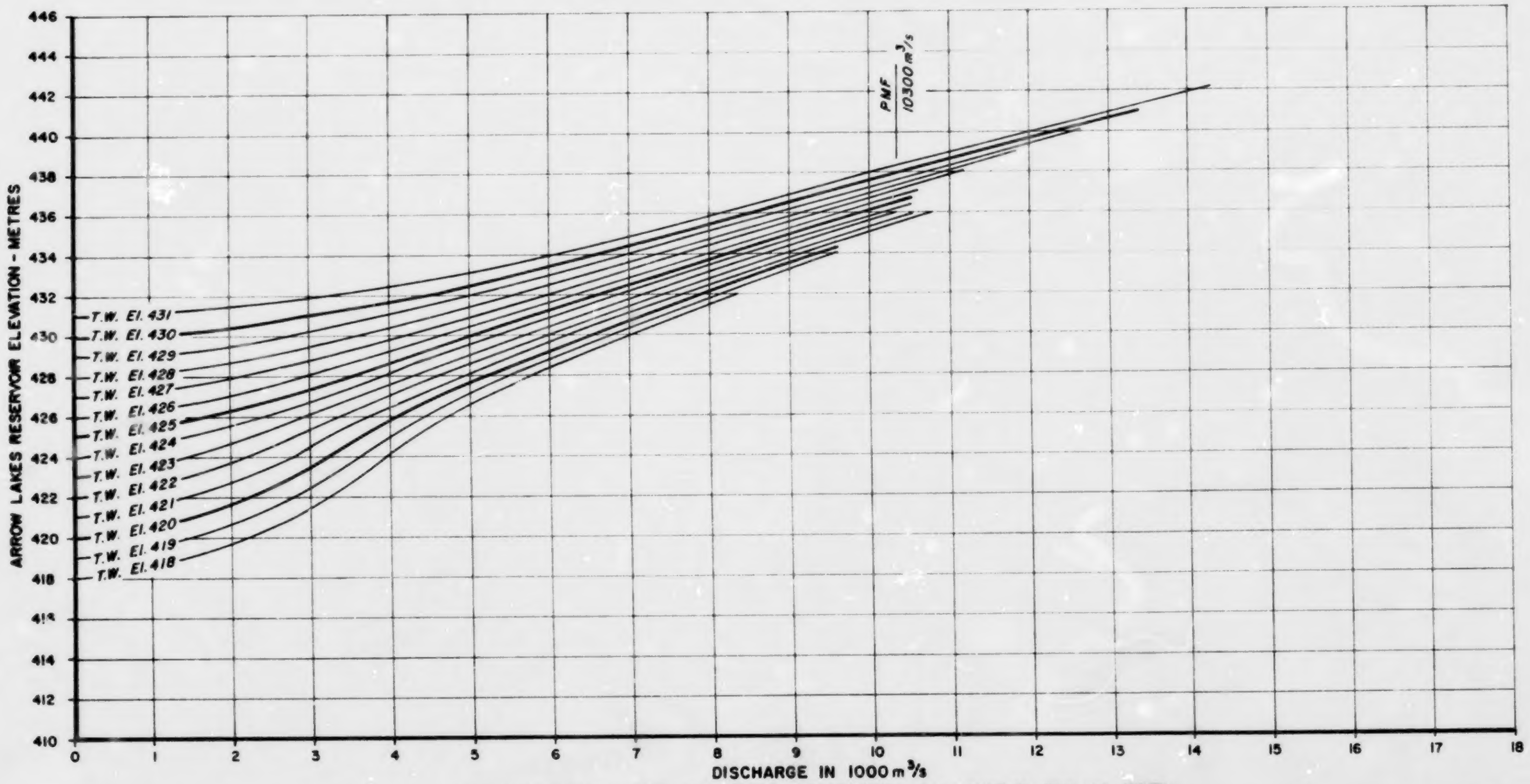
REPORT No H1613



SINGLE PORT - GATE FULLY OPEN



SINGLE SLUICEWAY



4 SLUICEWAYS AND 8 PORTS COMBINED - ALL GATES FULLY OPEN

NOTE:

TAILWATER LEVELS REFER TO RECORDING GAUGE LOCATED ON RIGHT SIDE OF LOCK.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

SLUICEWAY AND LOW LEVEL PORTS RATING CURVES

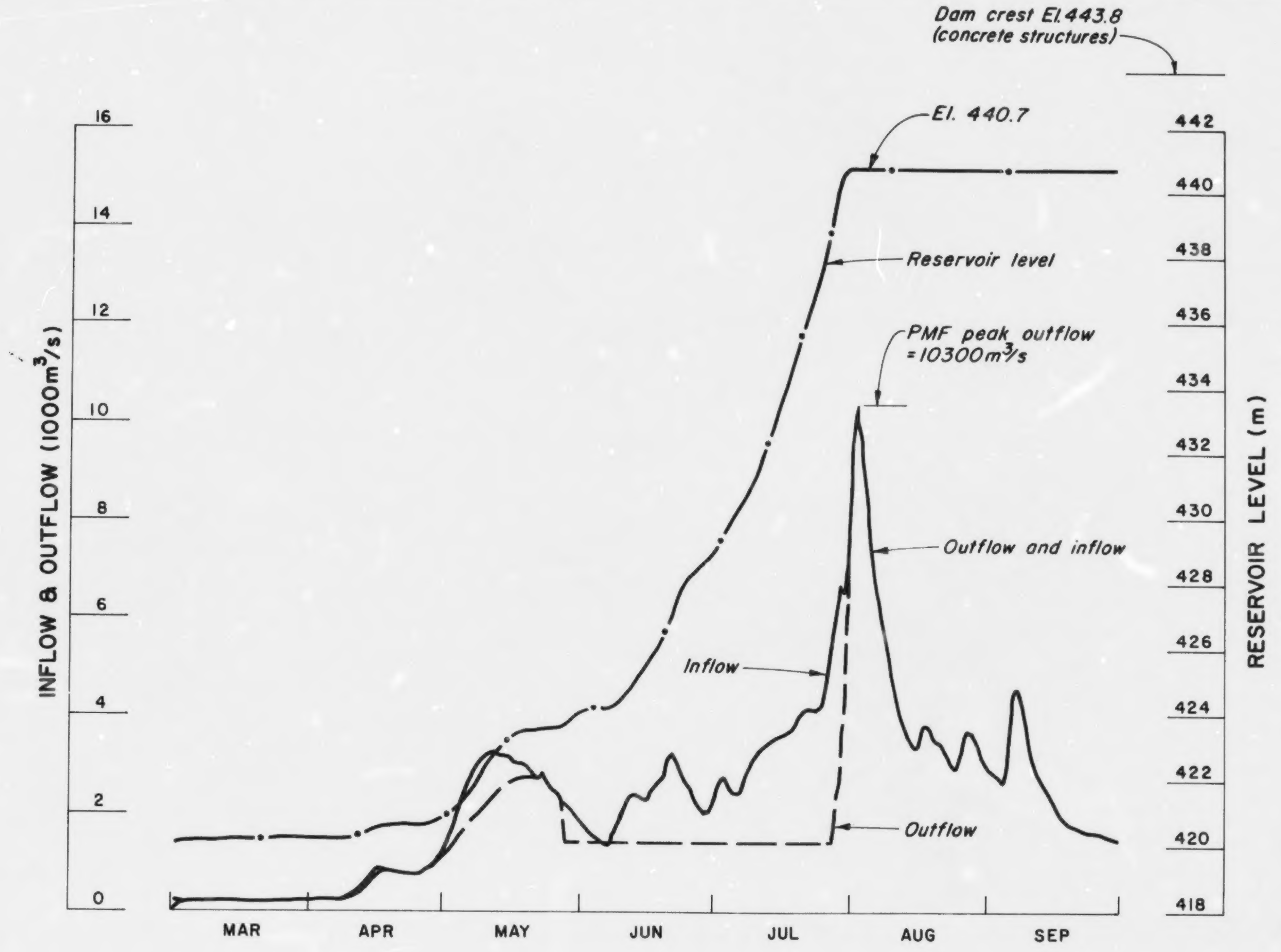
DATE MAY 1983

FIG. 3-6

DWN SM/AH

DWG No. 240-C14-D280

REPORT No. H1613



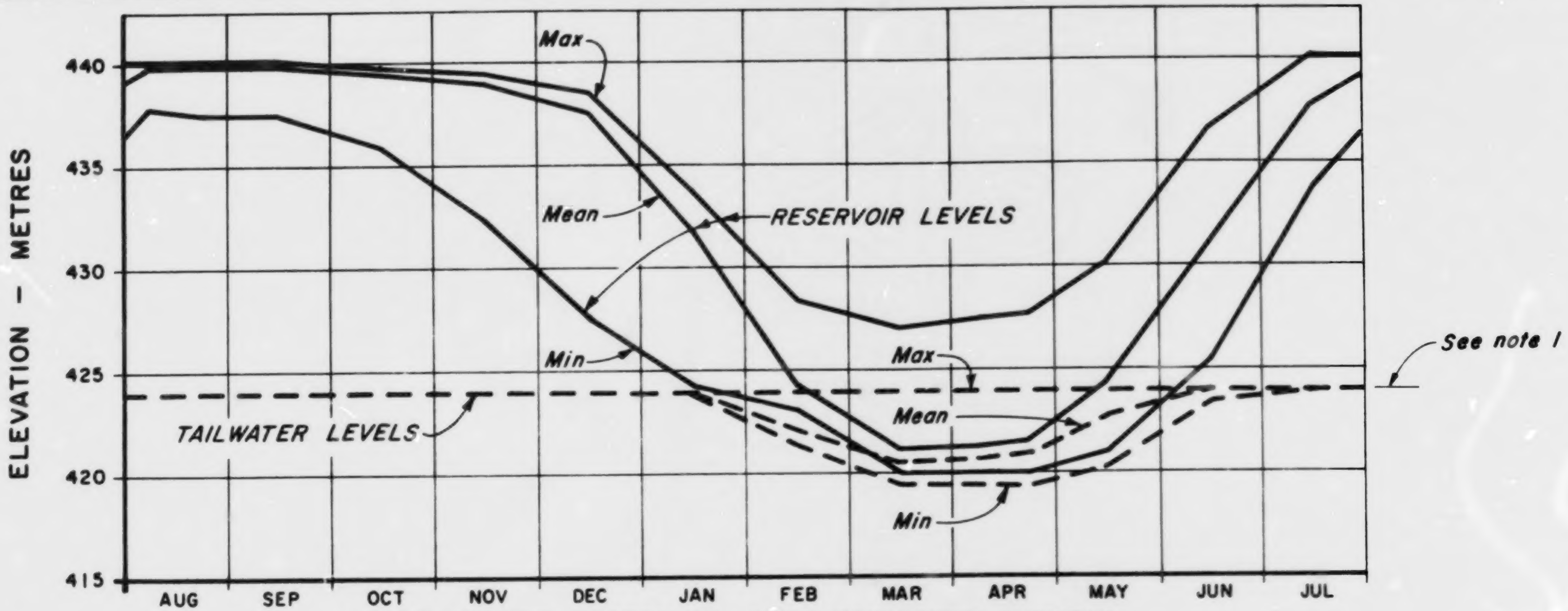
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

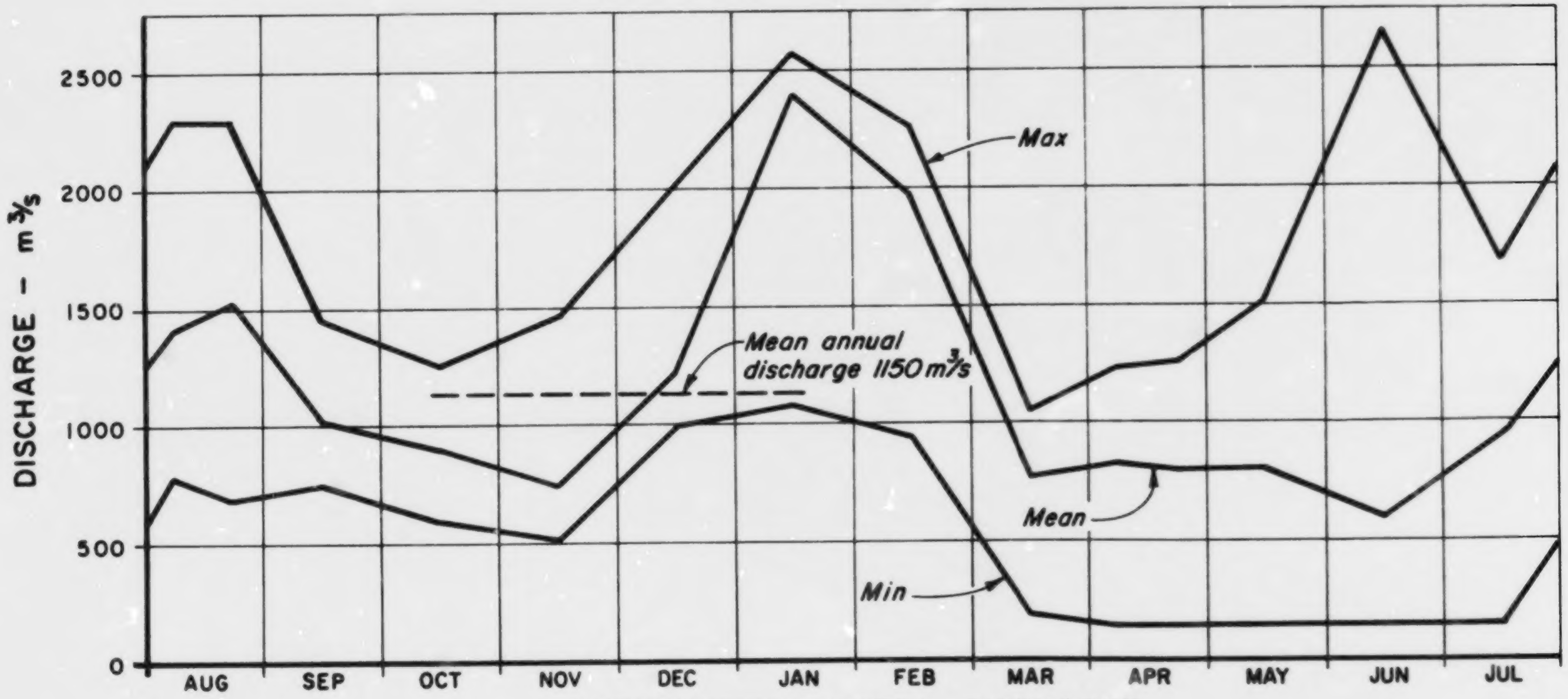
PROBABLE MAXIMUM FLOOD HYDROGRAPH

DATE MAY 1983	FIG. 4-1
DWN SM	DWG. No 240-C14-B281

REPORT No H1613



KEENLEYSIDE RESERVOIR AND TAILWATER LEVELS



KEENLEYSIDE TOTAL DISCHARGE

NOTE:

1. KEENLEYSIDE TAILWATER LEVELS ARE BASED ON A MURPHY CREEK PROJECT RESERVOIR ELEVATION LIMIT OF 424.0 m AT CASTLEGAR.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

TYPICAL RESERVOIR LEVELS & DISCHARGE HYDROGRAPHS - REGIME I

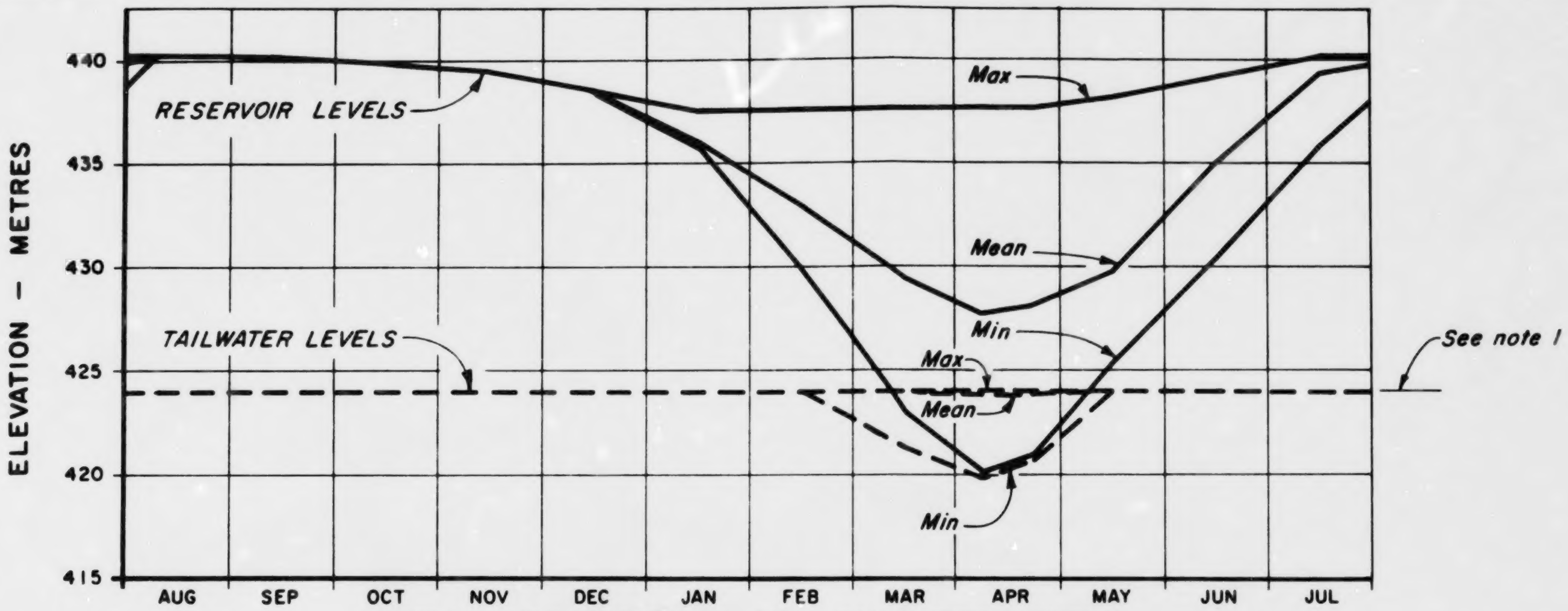
DATE MAY 1983

FIG. 4-2

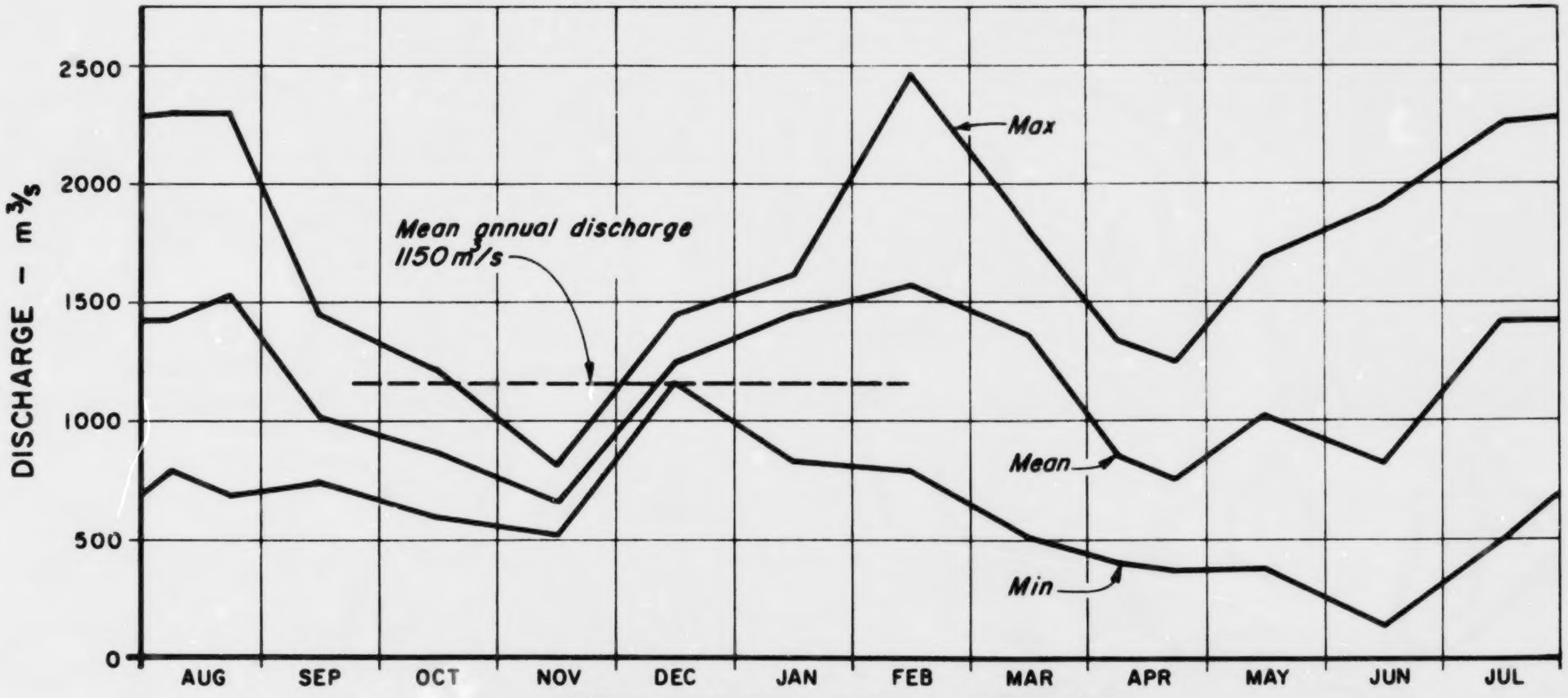
DWN KL

DWG. No 240-C14-B282

REPORT No H1613



KEENLEYSIDE RESERVOIR AND TAILWATER LEVELS



KEENLEYSIDE TOTAL DISCHARGE

NOTE:

1. KEENLEYSIDE TAILWATER LEVELS ARE BASED ON A MURPHY CREEK PROJECT RESERVOIR ELEVATION LIMIT OF 424.0 m AT CASTLEGAR.

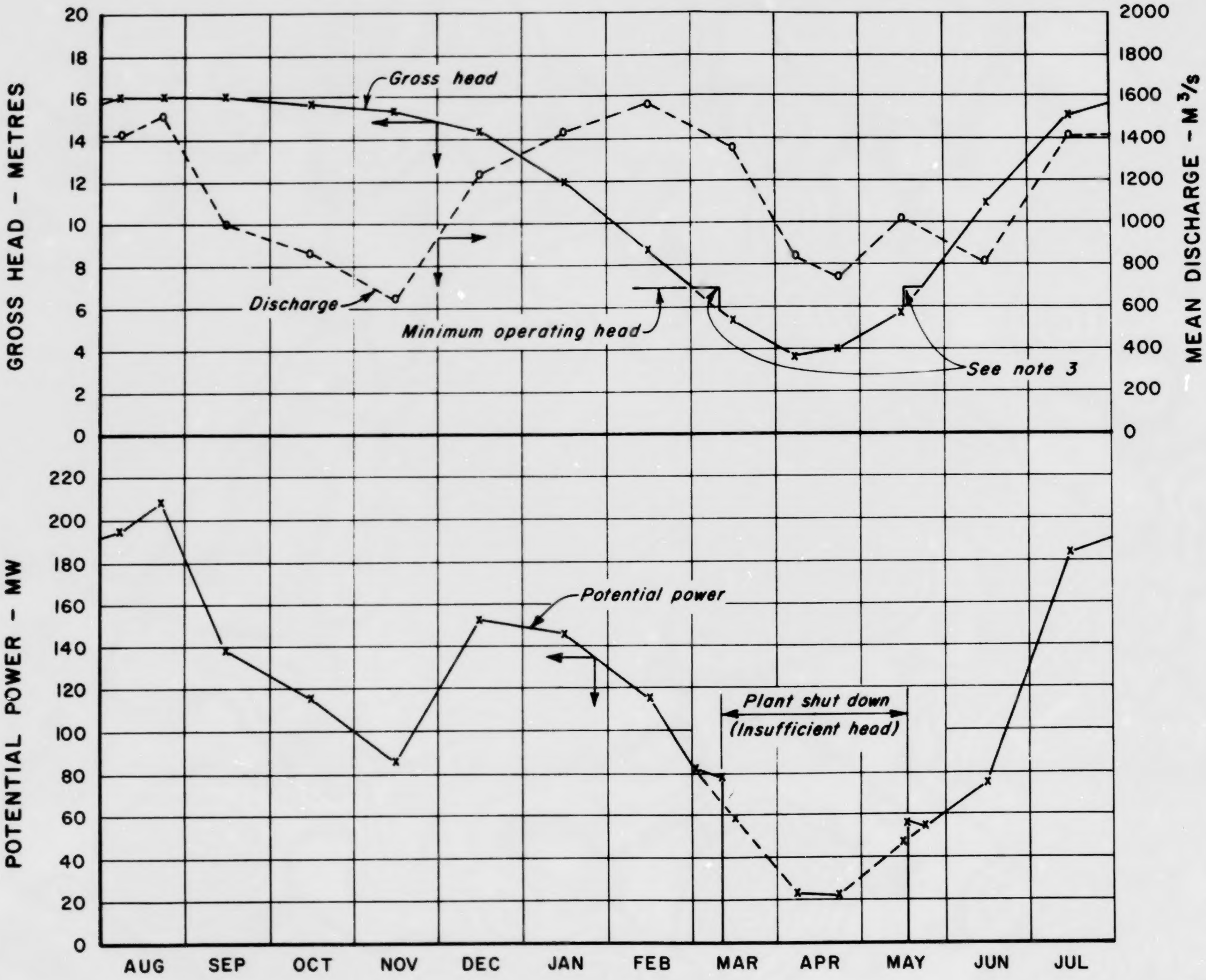
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

TYPICAL RESERVOIR LEVELS & DISCHARGE HYDROGRAPHS - REGIME 2

DATE MAY 1983	FIG. 4-3
DWN KL	DWG No 240-C14-B283

REPORT No H1613



NOTES:

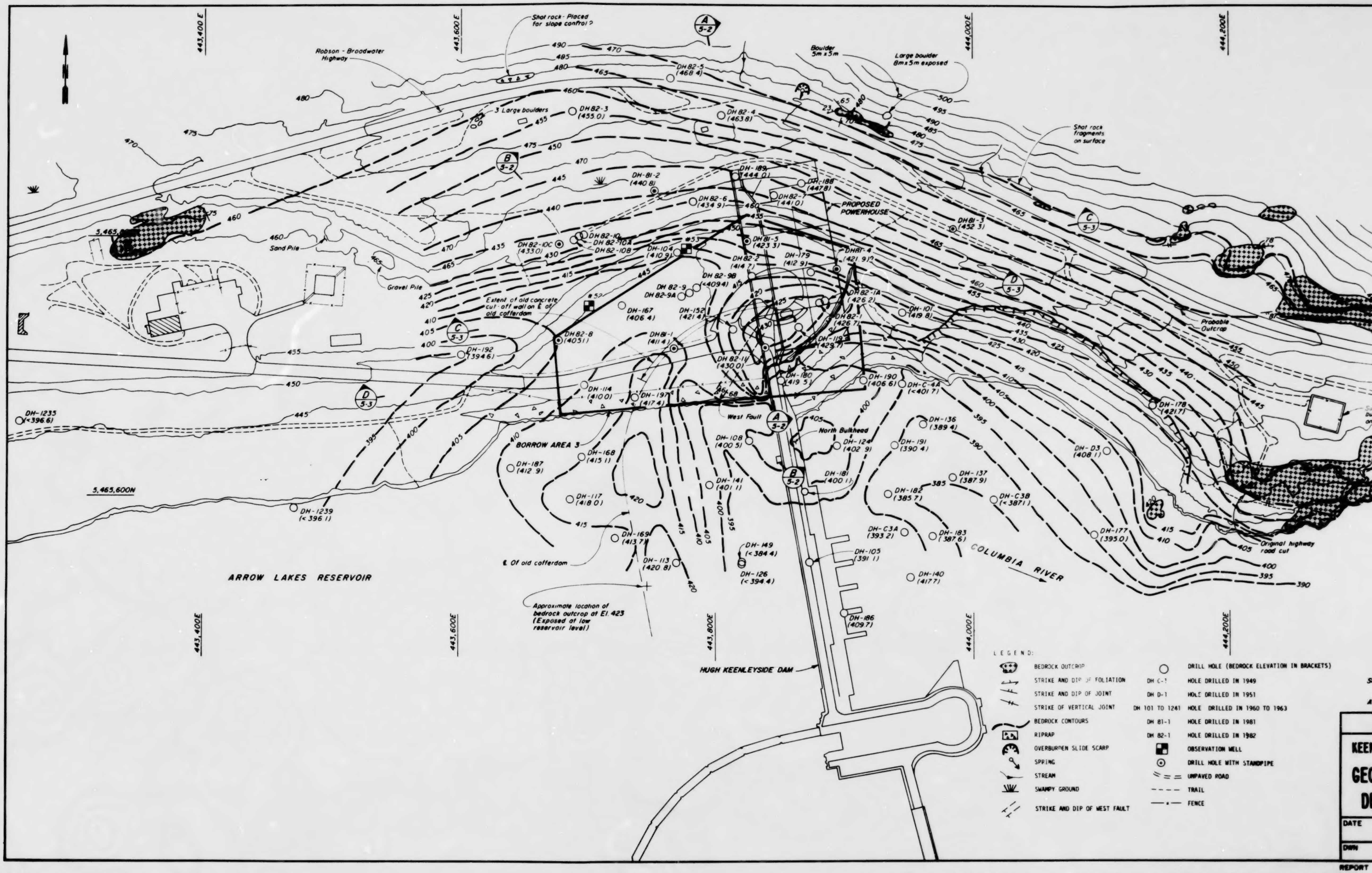
1. POTENTIAL POWER IS BASED ON 35 YEAR MEAN MONTHLY VALUES OF GROSS HEAD AND TOTAL DISCHARGE. AN AVERAGE HEAD LOSS OF 0.6 m AND AND OVERALL PLANT EFFICIENCY OF 0.90 HAVE BEEN ASSUMED.
2. THE EFFECTS OF RESERVOIR SURCHARGE IN HIGH RUNOFF YEARS ARE NOT INCLUDED.
3. TAILWATER (MURPHY RES.) LOWERED TO MAINTAIN SUFFICIENT HEAD FOR GENERATION AT KEENLEYSIDE.

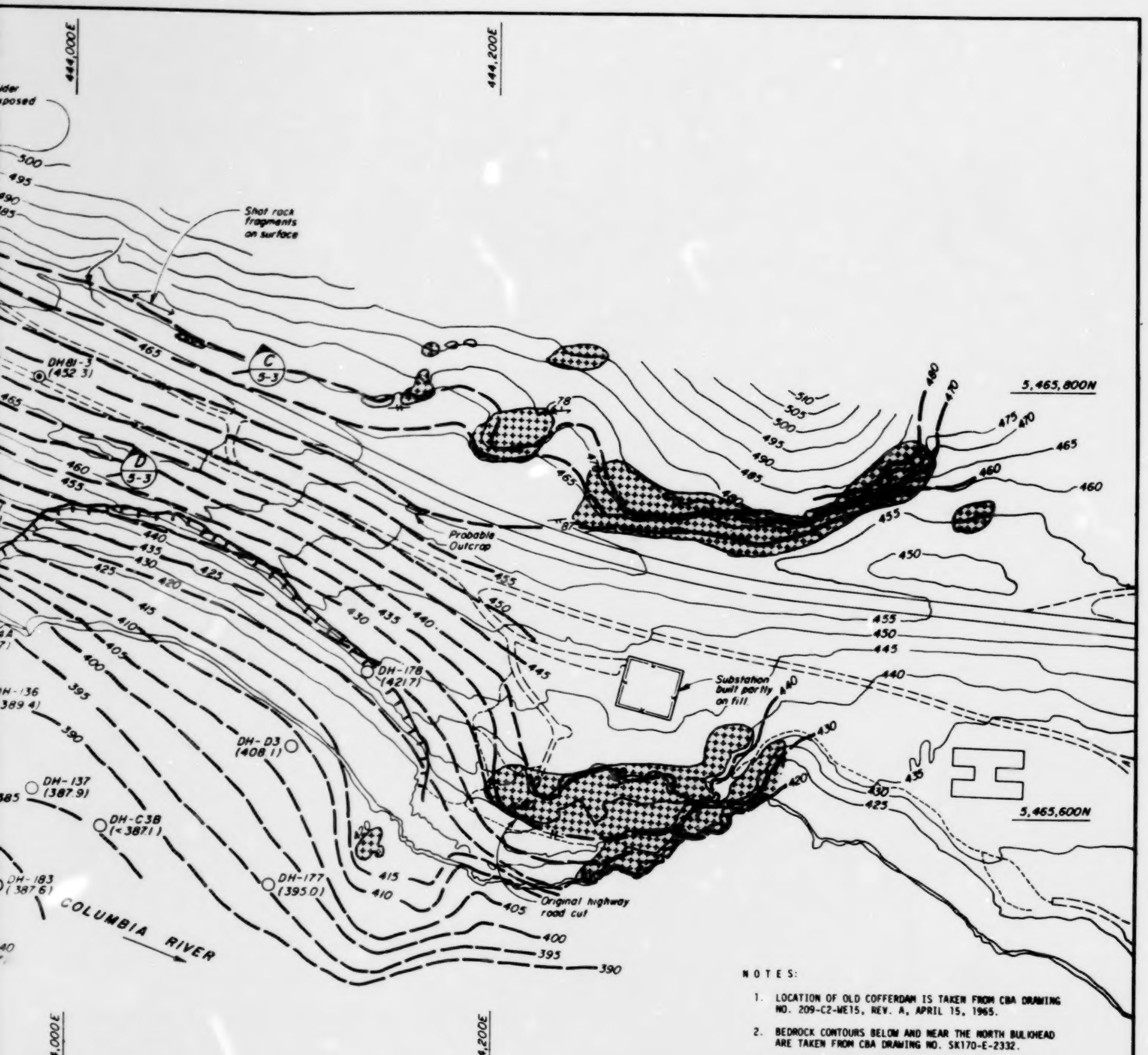
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
MEAN MONTHLY DISCHARGE,
HEAD AND POWER
REGIME 2

DATE MAY 1983	FIG. 4-4
DWN DJ	DWG. No 240-C14-B284

REPORT No H1613


443,400 E
443,600 E
443,800 E
444,000 E
444,200 E
Shot rock - Placed for slope control ?
A 5-2
Robson - Broadwater Highway
Boulder 5m x 5m
Large boulder 8m x 5m exposed
Shot rock fragments on surface
DH 82-5 (468.4)
3 Large boulders
DH 82-3 (455.0)
DH 82-4 (463.8)
B 5-2
DH-81-2 (440.8)
DH-189 (444.0)
DH-188 (447.8)
DH 82-6 (434.9)
DH 82-7 (441.0)
PROPOSED POWERHOUSE
DH 81-3 (452.3)
C 5-3
5,465,800N
Sand Pile
Gravel Pile
DH 82-10C (433.0)
DH 82-10
DH 82-10A
DH 82-10B
DH-104 (410.9)
#53
DH 81-5 (423.3)
DH 82-2 (414.7)
DH-179 (412.9)
DH81-4 (421.9)?
DH 82-9B (<409.4)
DH 82-9
DH 82-9A
D 5-3
Extent of old concrete cut-off wall on ℄ of old cofferdam
#52
DH-167 (406.4)
DH-152 (421.4)
DH 82-1A (426.2)
DH-101 (419.8)
DH 82-8 (405.1)
DH81-1 (411.4)
DH 82-1 (426.7)
DH-119 (429.7)
Probable Outcrop
C 5-3
DH-192 (394.6)
DH 82-11 (430.0)
DH-180 (419.5)
DH-190 (406.6)
DH-C-4A (<401.7)
DH-114 (410.0)
DH-197 (417.4)
D 5-3
West Fault
A 5-2
DH-178 (421.7)
DH-1235 (<396.6)
DH-136 (389.4)
North Bulkhead
BORROW AREA 3
DH-108 (400.5)
DH-124 (402.9)
DH-191 (390.4)
DH-D3 (408.1)
DH-168 (415.1)
DH-187 (412.9)
B 5-2
DH-181 (400.1)
DH-137 (387.9)
DH-141 (401.1)
DH-182 (385.7)
DH-C3B (<387.1)
5,465,600N
DH-117 (418.0)
DH-1239 (<396.1)
DH-C3A (393.2)
DH-177 (395.0)
DH-169 (413.7)
DH-149 (<384.4)
DH-183 (387.6)
Original highway road cut
COLUMBIA RIVER
DH-113 (420.8)
DH-105 (391.1)
℄ Of old cofferdam
DH-126 (<394.4)
DH-140 (417.7)
ARROW LAKES RESERVOIR
Approximate location of bedrock outcrop at El. 423 (Exposed at low reservoir level)
DH-186 (409.7)
HUGH KEENLEYSIDE DAM
LEGEND:
BEDROCK OUTCROP
STRIKE AND DIP OF FOLIATION
STRIKE AND DIP OF JOINT
STRIKE OF VERTICAL JOINT
BEDROCK CONTOURS
RIPRAP
OVERBURDEN SLIDE SCARP
SPRING
STREAM
SWAMPY GROUND
STRIKE AND DIP OF WEST FAULT
DRILL HOLE (BEDROCK ELEVATION IN BRACKETS)
DH C-1 HOLE DRILLED IN 1949
DH D-1 HOLE DRILLED IN 1951
DH 101 TO 1241 HOLE DRILLED IN 1960 TO 1963
DH 81-1 HOLE DRILLED IN 1981
DH 82-1 HOLE DRILLED IN 1982
OBSERVATION WELL
DRILL HOLE WITH STANDPIPE
UNPAVED ROAD
TRAIL
FENCE
DATE
DWN
REPORT


444,000E
444,200E
Shot rock fragments on surface
DH81-3 (452.3)
C 5-3
D 5-3
5,465,800N
5,465,600N
Probable Outcrop
Substation built partly on fill
DH-178 (421.7)
DH-136 (389.4)
DH-D3 (408.1)
DH-137 (387.9)
DH-C38 (<387.1)
DH-177 (395.0)
DH-183 (387.6)
COLUMBIA RIVER
Original highway road cut
510
505
500
495
490
485
480
475
470
465
460
455
450
445
440
435
430
425
420
415
410
405
400
395
390

LEGEND:

BEDROCK OUTCROP	
STRIKE AND DIP OF FOLIATION	DH C-1 HOLE DRILLED IN 1949
STRIKE AND DIP OF JOINT	DH D-1 HOLE DRILLED IN 1951
STRIKE OF VERTICAL JOINT	DH 101 TO 1241 HOLE DRILLED IN 1960 TO 1963
BEDROCK CONTOURS	DH 81-1 HOLE DRILLED IN 1981
RIPRAP	DH 82-1 HOLE DRILLED IN 1982
OVERBURDEN SLIDE SCARP	OBSERVATION WELL
SPRING	DRILL HOLE WITH STANDPIPE
STREAM	UNPAVED ROAD
SWAMPY GROUND	TRAIL
STRIKE AND DIP OF WEST FAULT	FENCE

○ DRILL HOLE (BEDROCK ELEVATION IN BRACKETS)

NOTES:

1. LOCATION OF OLD COFFERDAM IS TAKEN FROM CBA DRAWING NO. 209-C2-WE15, REV. A, APRIL 15, 1965.
2. BEDROCK CONTOURS BELOW AND NEAR THE NORTH BULKHEAD ARE TAKEN FROM CBA DRAWING NO. SK170-E-2332.
3. LOCATION OF WEST FAULT TAKEN FROM CBA DRAWING NO. SK170-B-2316.
4. LIMITS OF BORROW AREA 3 ARE ONLY APPROXIMATE. ADDITIONAL MATERIAL MAY BE OBTAINED OUTSIDE THESE LIMITS.

Scale: 25 0 25 50 75 100 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

GEOLOGIC PLAN AND DRILL HOLE LOCATIONS

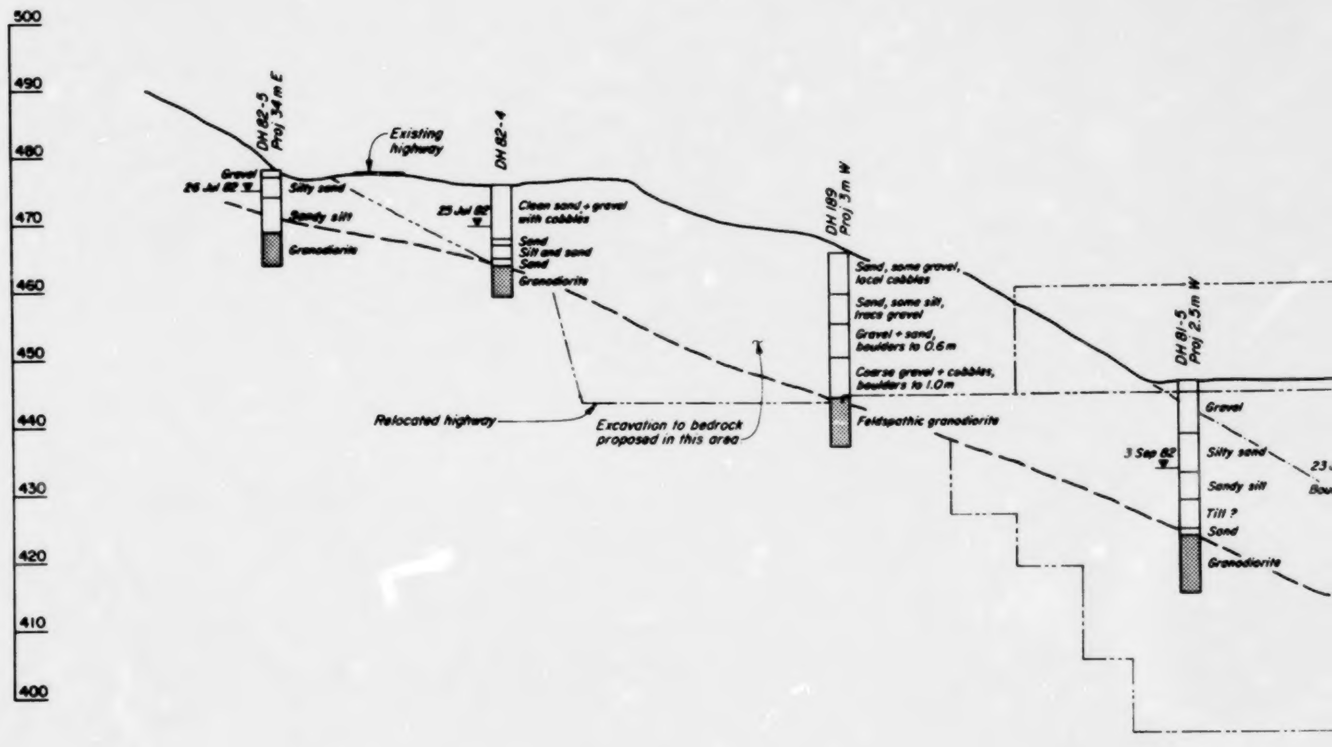
DATE MAY 1983

FIG. 5-1

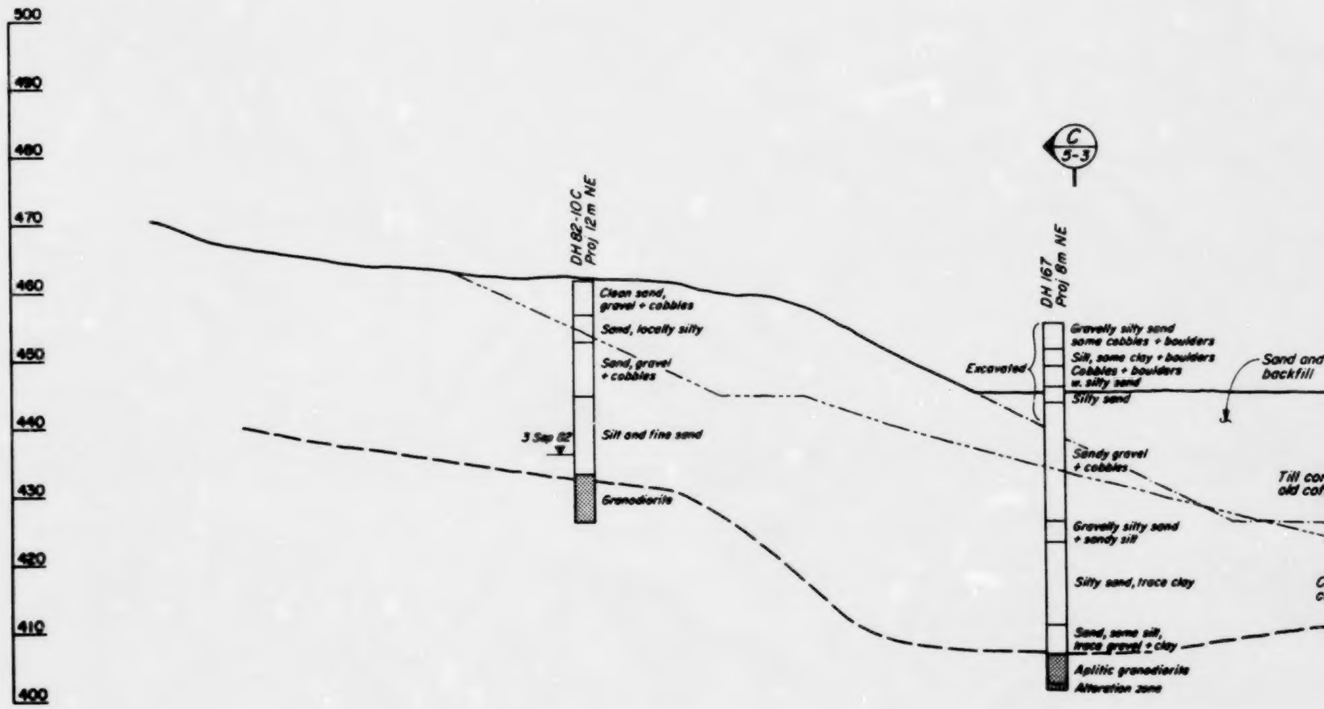
DWN RKW

DWG No. 240-C14-U285

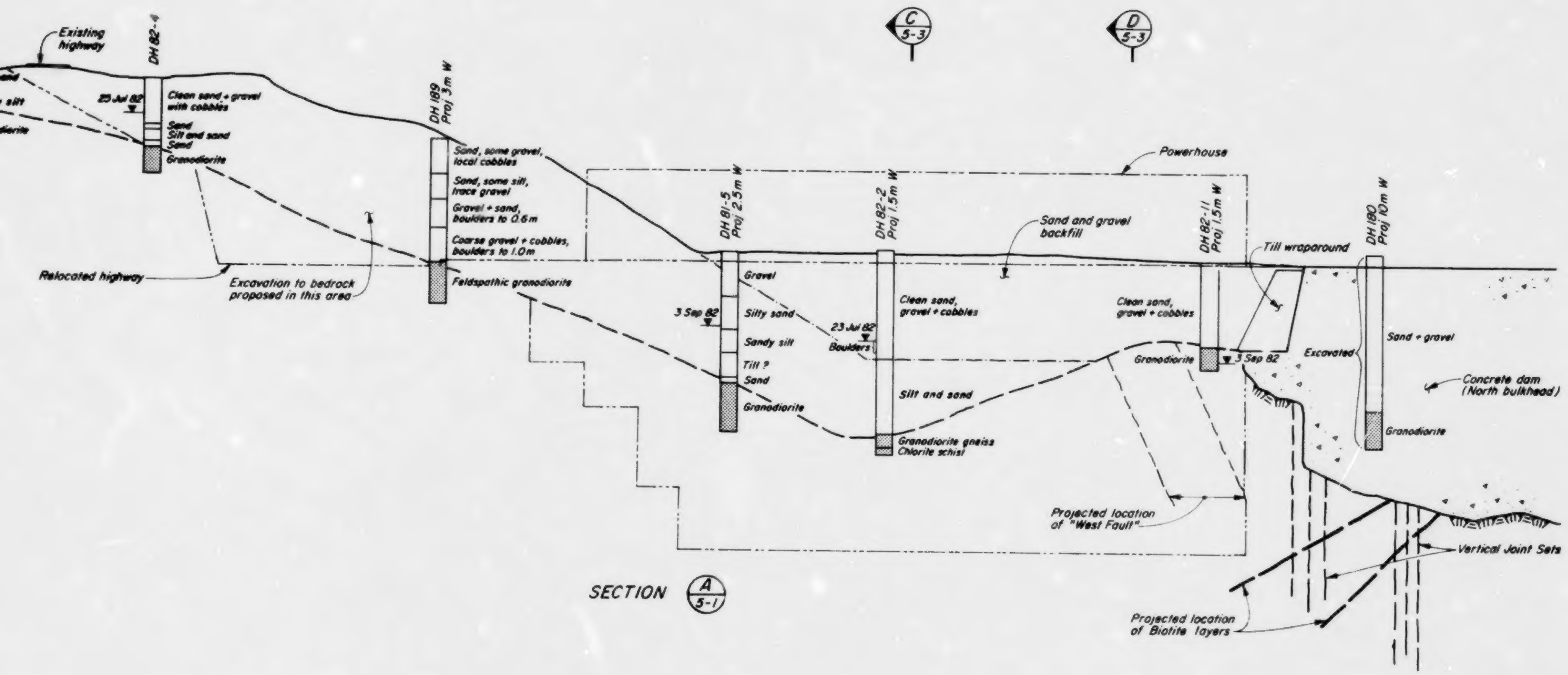
REPORT No. H1613


500
490
480
470
460
450
440
430
420
410
400
DH 82-5 Proj 34m E
Gravel
26 Jul 82
Silty sand
Sandy silt
Granodiorite
Existing highway
DH 82-4
25 Jul 82
Clean sand + gravel with cobbles
Sand
Silt and sand
Sand
Granodiorite
DH 189 Proj 3m W
Sand, some gravel, local cobbles
Sand, some silt, trace gravel
Gravel + sand, boulders to 0.6m
Coarse gravel + cobbles, boulders to 1.0m
Feldspathic granodiorite
Relocated highway
Excavation to bedrock proposed in this area
DH 81-5 Proj 2.5m W
Gravel
3 Sep 82
Silty sand
Sandy silt
Till ?
Sand
Granodiorite
23
Bou

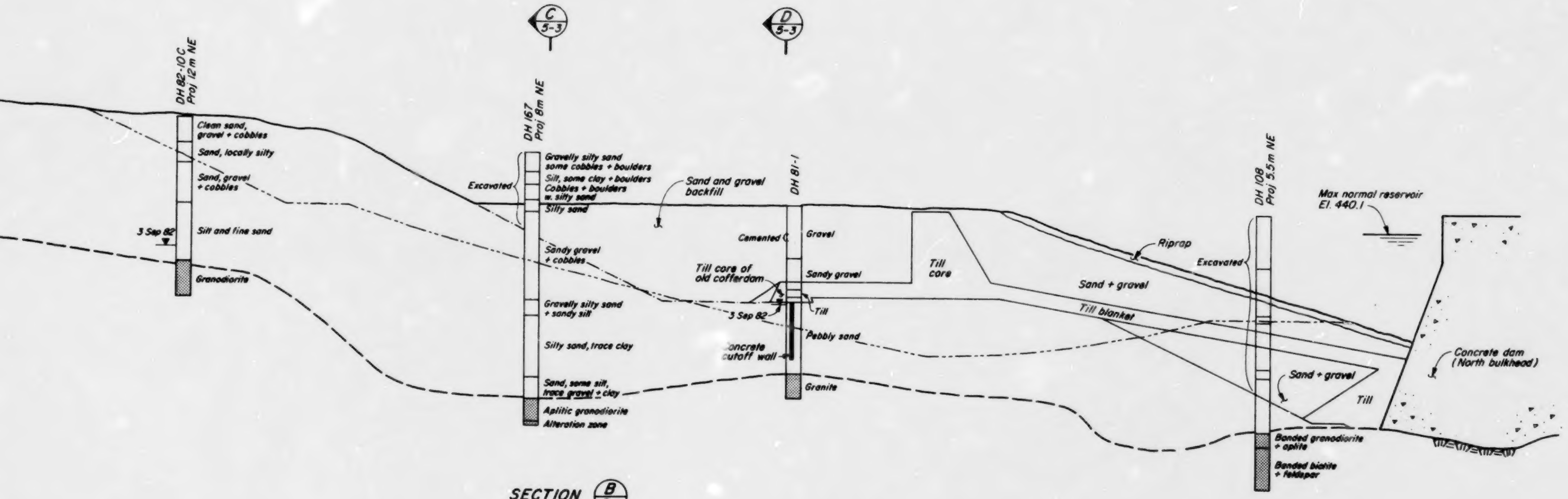
SECTION A/5-1


500
490
480
470
460
450
440
430
420
410
400
C 5-3
DH 82-10C Proj 12m NE
Clean sand, gravel + cobbles
Sand, locally silty
Sand, gravel + cobbles
3 Sep 82
Silt and fine sand
Granodiorite
DH 167 Proj 8m NE
Excavated
Gravelly silty sand some cobbles + boulders
Silt, some clay + boulders
Cobbles + boulders w. silty sand
Silty sand
Sandy gravel + cobbles
Gravelly silty sand + sandy silt
Silty sand, trace clay
Sand, some silt, trace gravel + clay
Aplitic granodiorite
Alteration zone
Sand and backfill
Till co old co

SECTION B/5-1


C 5-3
D 5-3
Existing highway
DH 82-4
25 Jul 82
Clean sand + gravel with cobbles
Sand
Silt and sand
Sand
Granodiorite
silt
Relocated highway
Excavation to bedrock proposed in this area
DH 189 Proj 3m W
Sand, some gravel, local cobbles
Sand, some silt, trace gravel
Gravel + sand, boulders to 0.6m
Coarse gravel + cobbles, boulders to 1.0m
Feldspathic granodiorite
Powerhouse
DH 81-5 Proj 2.5m W
Gravel
3 Sep 82
Silty sand
Sandy silt
Till ?
Sand
Granodiorite
DH 82-2 Proj 1.5m W
23 Jul 82
Boulders
Clean sand, gravel + cobbles
Silt and sand
Granodiorite gneiss
Chlorite schist
Sand and gravel backfill
DH 82-11 Proj 1.5m W
Clean sand, gravel + cobbles
Granodiorite
3 Sep 82
Till wraparound
Excavated
DH 180 Proj 10m W
Sand + gravel
Granodiorite
Concrete dam (North bulkhead)
Projected location of "West Fault"
Vertical Joint Sets
Projected location of Biotite layers

SECTION A/5-1


C 5-3
D 5-3
DH 82-10C Proj 12m NE
Clean sand, gravel + cobbles
Sand, locally silty
Sand, gravel + cobbles
3 Sep 82
Silt and fine sand
Granodiorite
DH 167 Proj 8m NE
Excavated
Gravelly silty sand some cobbles + boulders
Silt, some clay + boulders
Cobbles + boulders w. silty sand
Silty sand
Sandy gravel + cobbles
Gravelly silty sand + sandy silt
Silty sand, trace clay
Sand, some silt, trace gravel + clay
Aplitic granodiorite
Alteration zone
Sand and gravel backfill
DH 81-1
Cemented
Gravel
Sandy gravel
Till core of old cofferdam
Till
3 Sep 82
Pebbly sand
Concrete cutoff wall
Granite
Till core
Riprap
Sand + gravel
Till blanket
DH 108 Proj 5.5m NE
Excavated
Sand + gravel
Till
Banded granodiorite + aplite
Banded biotite + feldspar
Max normal reservoir El. 440.1
Concrete dam (North bulkhead)

SECTION B/5-1

LEGEND:

▨ BEDROCK
— — — ASSUMED BEDROCK SURFACE
BEDROCK SURFACE (EXPOSED OR BELOW CONCRETE DAM)
—·—·— APPROXIMATE LIMITS OF OLD EXCAVATION
—--— PROPOSED EXCAVATION FOR POWERHOUSE
▼ WATER LEVEL IN DRILL HOLE OR STANDPIPE WITH DATE OF READING INDICATED

NOTES:

1. DETAILS OF OLD EXCAVATIONS, COFFERDAM AND TILL CORE AND BLANKET ARE TAKEN FROM CBA DWG. NOS. 209-C2-WE14 TO WE16., AND 209-C2-WE20 TO WE25. EXACT LOCATIONS OF THESE FEATURES MAY VARY FROM THOSE SHOWN SINCE THE ABOVE DRAWINGS WERE NOT MARKED TO SHOW AS-BUILT LOCATIONS.

2. DETAILS OF GEOLOGY NEAR THE CONCRETE DAM ARE TAKEN FROM CBA DWG. NOS. SK170-D-2203 AND SK170-BX-2314.

Scale: 10 0 10 20 30 40 Metres

All dimensions are in metres, unless otherwise shown

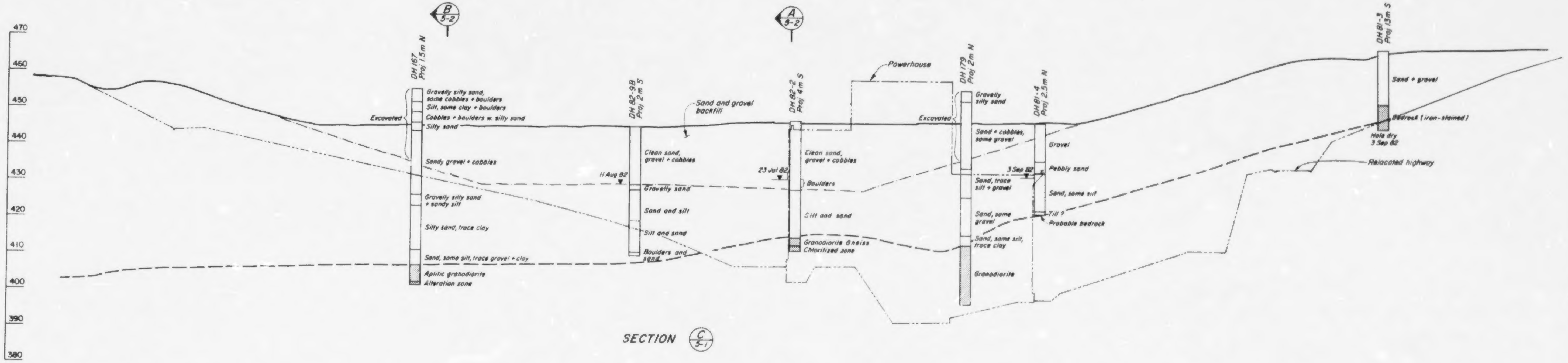
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

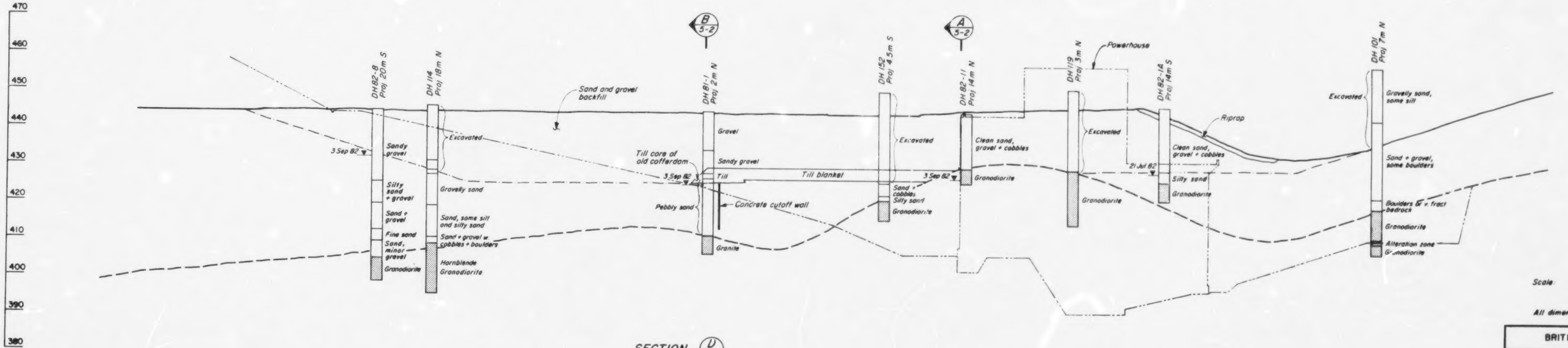
GEOLOGIC SECTIONS

SHEET 1

DATE MAY 1983
FIG. 5-2
DWN A.V.
DWG No. 240-C14-U286
REPORT No. H1613


470
460
450
440
430
420
410
400
390
380
B 5-2
A 5-2
DH 167 Proj 1.5m N
Excavated
Gravelly silty sand, some cobbles + boulders
Silt, some clay + boulders
Cobbles + boulders w. silty sand
Silty sand
Sandy gravel + cobbles
Gravelly silty sand + sandy silt
Silty sand, trace clay
Sand, some silt, trace gravel + clay
Aplitic granodiorite
Alteration zone
DH 82-9B Proj 2m S
Sand and gravel backfill
Clean sand, gravel + cobbles
11 Aug 82
Gravelly sand
Sand and silt
Silt and sand
Boulders and sand
DH 82-2 Proj 4m S
Clean sand, gravel + cobbles
23 Jul 82
Boulders
Silt and sand
Granodiorite Gneiss
Chloritized zone
Powerhouse
DH 179 Proj 2m N
Excavated
Gravelly silty sand
Sand + cobbles, some gravel
Sand, trace silt + gravel
Sand, some gravel
Sand, some silt, trace clay
Granodiorite
DH 81-4 Proj 2.5m N
Gravel
3 Sep 82
Pebbly sand
Sand, some silt
Till ?
Probable bedrock
DH 81-3 Proj 13m S
Sand + gravel
Bedrock (iron-stained)
Hole dry 3 Sep 82
Relocated highway

SECTION C 5-1


470
460
450
440
430
420
410
400
390
380
B 5-2
A 5-2
DH 82-8 Proj 20m S
3 Sep 82
Sandy gravel
Silty sand + gravel
Sand + gravel
Fine sand
Sand, minor gravel
Granodiorite
DH 114 Proj 18m N
Excavated
Gravelly sand
Sand, some silt and silty sand
Sand + gravel w cobbles + boulders
Hornblende Granodiorite
Sand and gravel backfill
DH 81-1 Proj 2m N
Gravel
Sandy gravel
Till core of old cofferdam
3 Sep 82
Till
Till blanket
Pebbly sand
Concrete cutoff wall
Granite
DH 152 Proj 4.5m S
Excavated
Sand + cobbles
Silty sand
Granodiorite
DH 82-11 Proj 14m N
3 Sep 82
Clean sand, gravel + cobbles
Granodiorite
Powerhouse
DH 119 Proj 3m N
Excavated
Granodiorite
DH 82-14 Proj 14m S
Riprap
Clean sand, gravel + cobbles
21 Jul 82
Silty sand
Granodiorite
DH 101 Proj 7m N
Excavated
Gravelly sand, some silt
Sand + gravel, some boulders
Boulders & = fract bedrock
Granodiorite
Alteration zone
Granodiorite

SECTION D 5-1

Scale 10 0

All dimensions are i

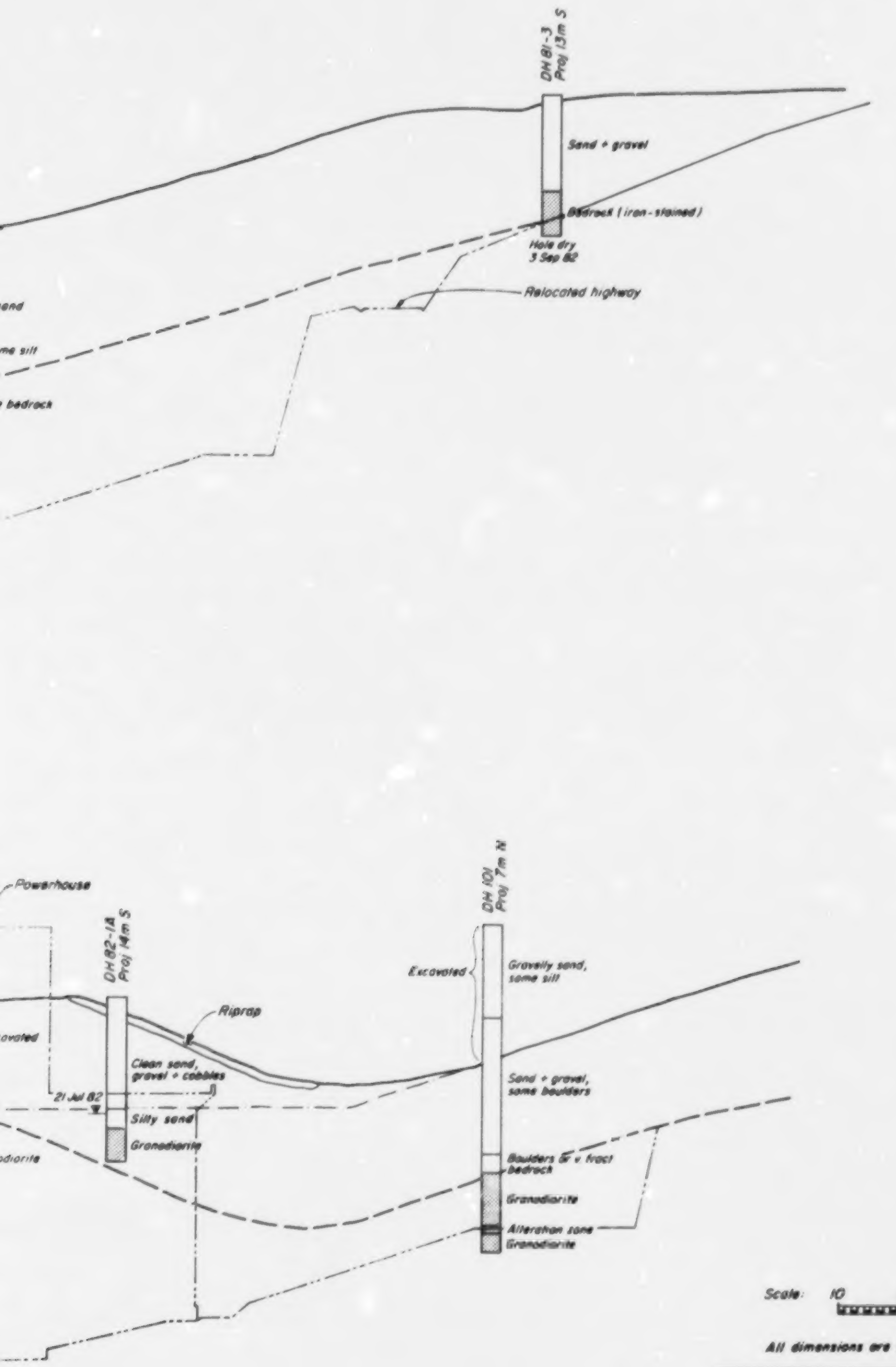
BRITISH COLU

KEENLEYSIDE POW

GEOLOGIC SE

DATE MAY 1983

DWN A.V.


DH 81-3
Proj 13m S
Sand + gravel
Bedrock (iron-stained)
Hole dry
3 Sep 82
Relocated highway
and
me silt
bedrock
Powerhouse
DH 82-1A
Proj 14m S
Riprap
cavated
Clean sand,
gravel + cobbles
21 Jul 82
Silty sand
Granodiorite
diorite
DH 101
Proj 7m N
Excavated
Gravelly sand,
some silt
Sand + gravel,
some boulders
Boulders & v fract
bedrock
Granodiorite
Alteration zone
Granodiorite

NOTES:

1. FOR NOTES AND LEGEND SEE FIG. 5-2

Scale: 10 0 10 20 30 40 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

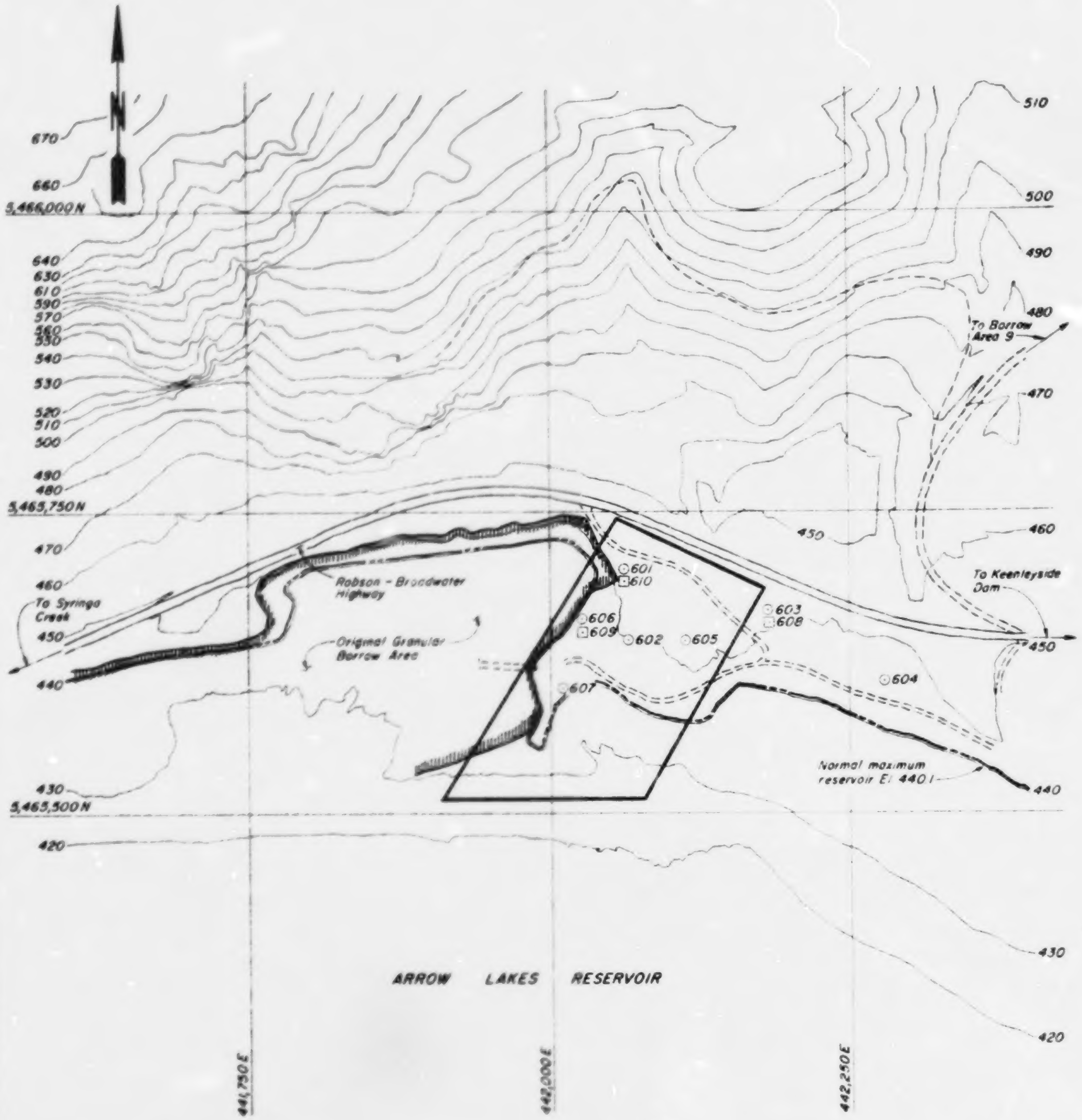
KEENLEYSIDE POWERPLANT PROJECT

GEOLOGIC SECTIONS

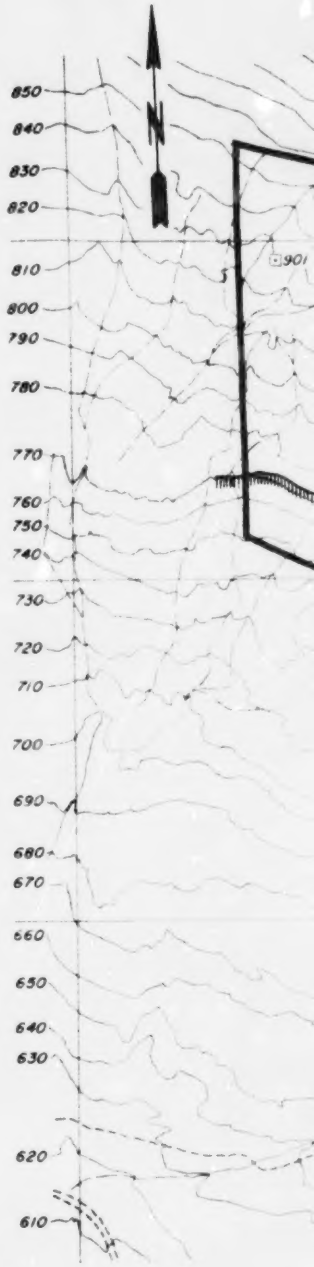
SHEET 2

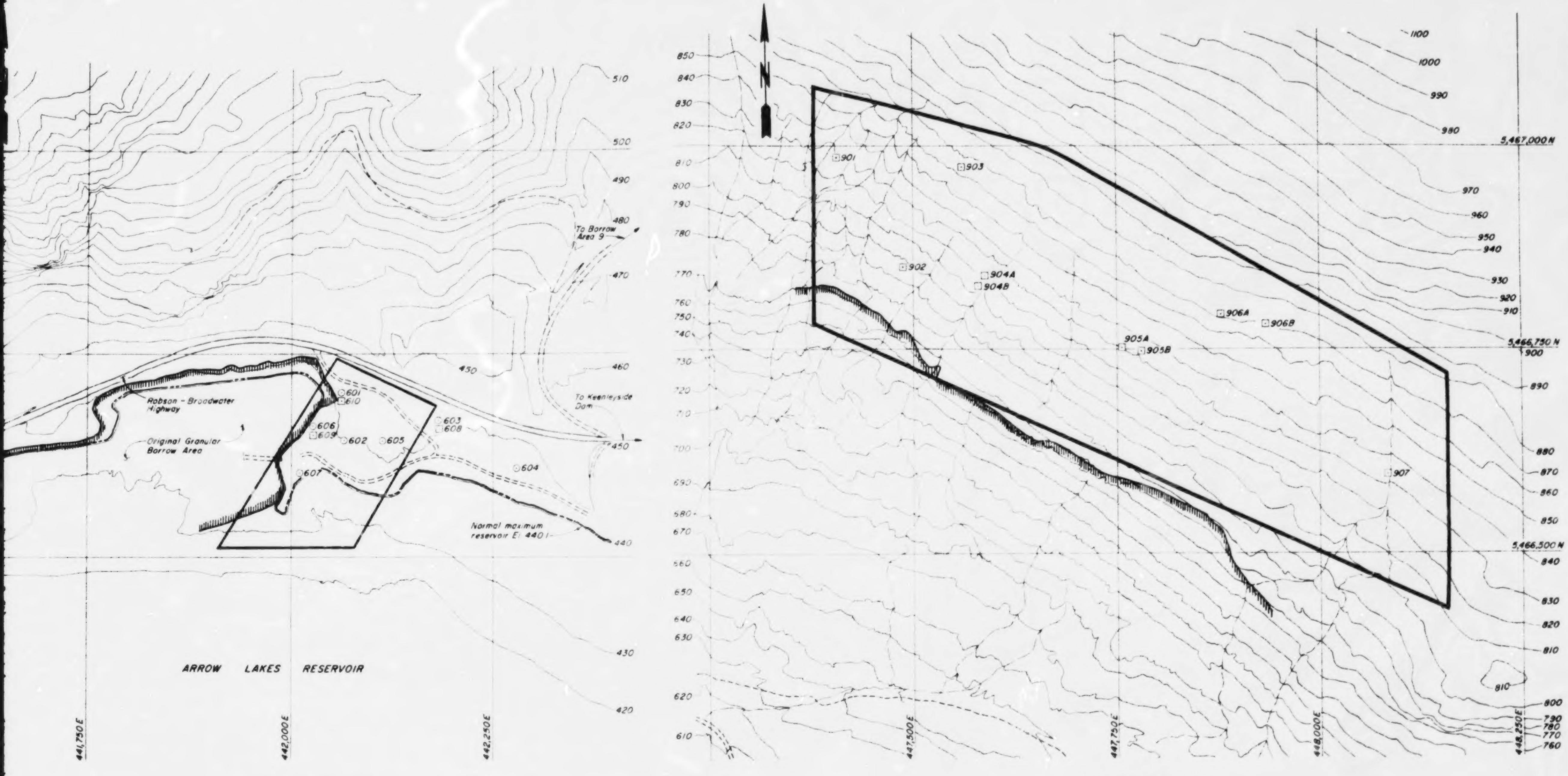
DATE	
MAY 1983	FIG. 5-3
DWN A.V.	DWG No 240-C14-U287

REPORT No. H1613


N
670
660
5,466,000 N
640
630
610
590
570
560
550
540
530
520
510
500
490
480
5,465,750 N
470
460
450
440
430
5,465,500 N
420
510
500
490
480
470
460
450
440
430
420
To Borrow Area 9
To Keenleyside Dam
To Syringa Creek
Robson - Broadwater Highway
Original Granular Borrow Area
601
610
603
608
606
609
602
605
604
607
Normal maximum reservoir El 440 l
ARROW LAKES RESERVOIR
441,750 E
442,000 E
442,250 E

BORROW AREA 6


N
850
840
830
820
810
800
790
780
770
760
750
740
730
720
710
700
690
680
670
660
650
640
630
620
610
901


N
To Borrow Area 9
To Keenleyside Dam
Robson - Broadwater Highway
Original Granular Borrow Area
Normal maximum reservoir El. 440.1
ARROW LAKES RESERVOIR
601
610
606
609
602
605
603
608
604
607
901
903
902
904A
904B
906A
906B
905A
905B
907
441,750E
442,000E
442,250E
447,500E
447,750E
448,000E
448,250E
5,467,000 N
5,466,750 N
5,466,500 N
510
500
490
480
470
460
450
440
430
420
1100
1000
990
980
970
960
950
940
930
920
910
900
890
880
870
860
850
840
830
820
810
800
790
780
770
760
750
740
730
720
710
700
690
680
670
660
650
640
630
620
610

BORROW AREA 6

BORROW AREA 9
(BALFOUR TILL PIT)

Scale 50 0 50 100 150 200 Metres

All dimensions are in metres, unless otherwise shown

NOTES:

1. FOR LOCATION PLAN SEE FIG. 9-3.
2. FOR BORROW AREA 3 SEE FIG. 5-1.
3. ONLY 1982 DRILL HOLES AND TEST PITS SHOWN.
4. FOR ADDITIONAL DETAILS SEE REPORT H1582.

LEGEND:

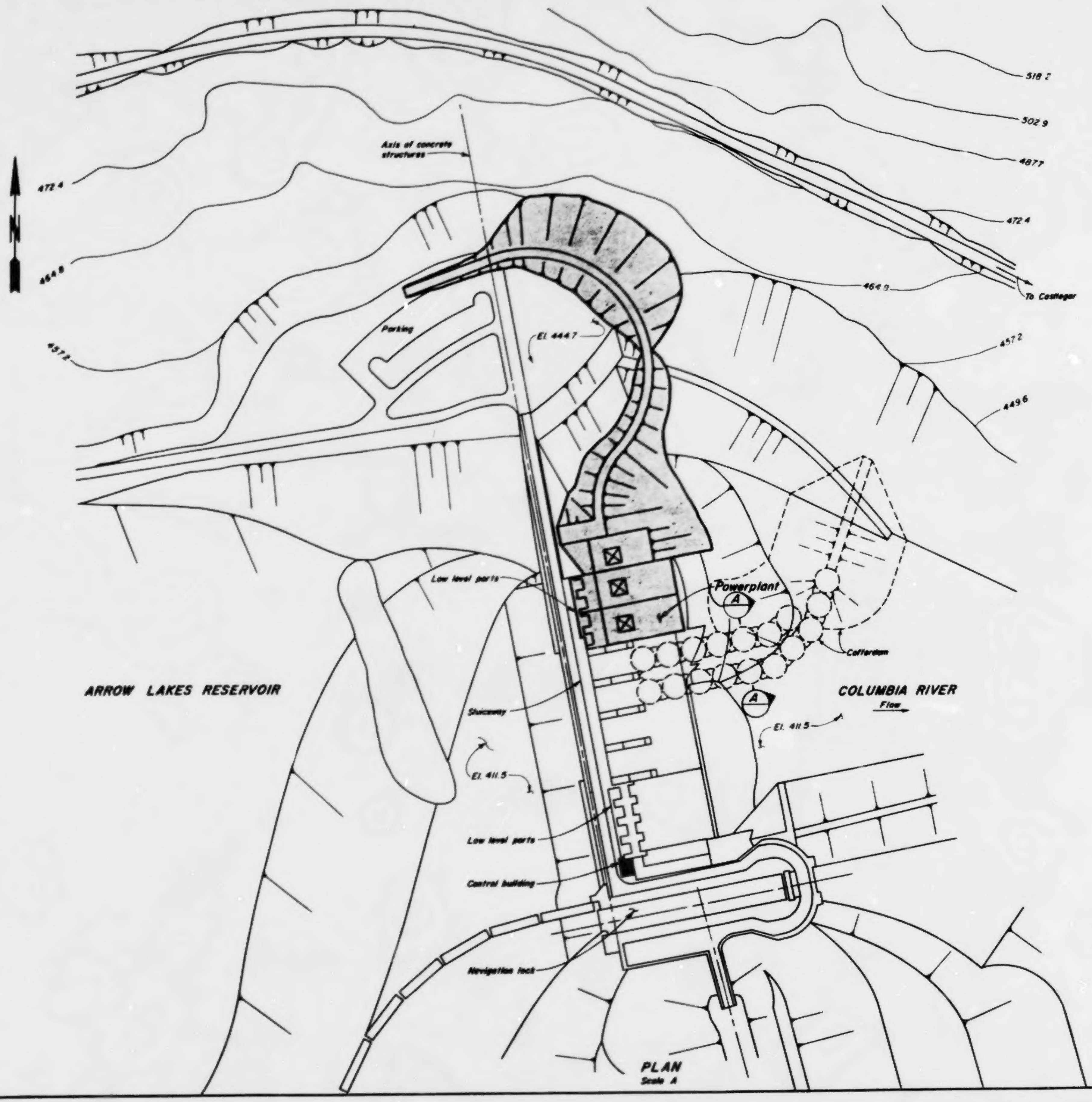
⊡ 903	TEST PIT TP82-903 (1982)
⊙ 606	BECKER DRILL HOLE DH82-606 (1982)
▨	EXISTING EXCAVATION FACE

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

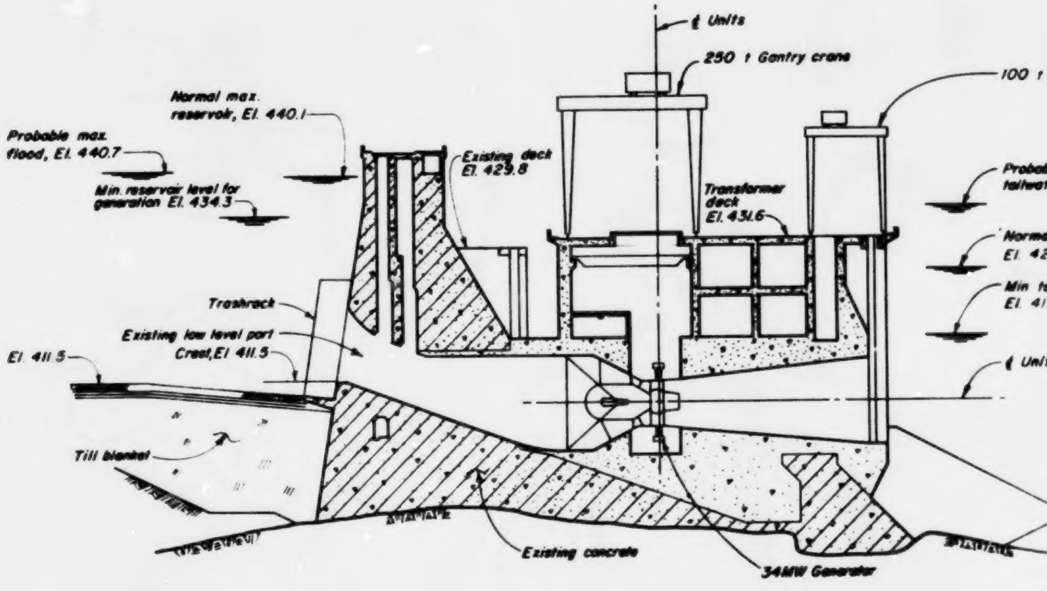
KEENLEYSIDE POWERPLANT PROJECT
1982 GEOTECHNICAL INVESTIGATIONS
CONSTRUCTION MATERIALS
DRILL HOLE & TEST PIT LOCATIONS

DATE MAY 1983	FIG. 5-4
DWN BE	DWG No. 240-C14-D288

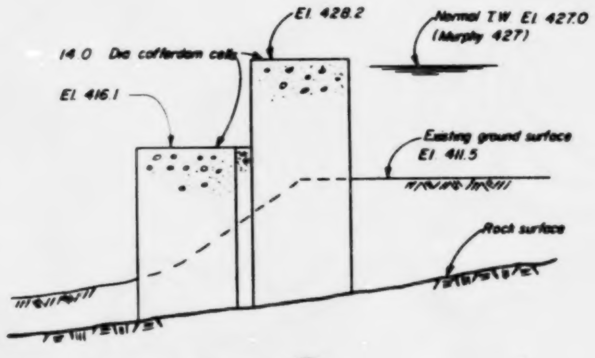
REPORT No


518.2
502.9
487.7
472.4
464.8
457.2
449.6
N
To Castlegar
Axis of concrete structures
Parking
El. 444.7
Low level ports
Powerplant
A
Cofferdam
ARROW LAKES RESERVOIR
COLUMBIA RIVER
Flow
Sluiceway
El. 411.5
Low level ports
Control building
Navigation lock

PLAN
Scale A


℄ Units
250 t Gantry crane
100 t
Normal max. reservoir, El. 440.1
Probable max. flood, El. 440.7
Min. reservoir level for generation El. 434.3
Existing deck El. 429.8
Transformer deck El. 431.6
Probab tailwat
Norma El. 42
Min t El. 41
℄ Unit
Trashrack
Existing low level port Crest, El 411.5
El. 411.5
Till blanket
Existing concrete
34MW Generator

SECTION THROUGH POWERPLANT
Scale B


14.0 Dia cofferdam cells
El. 428.2
Normal T.W. El. 427.0 (Murphy 427)
El. 416.1
Existing ground surface El. 411.5
Rock surface

SECTION A
Scale B

NOTES:

1. ARRANGEMENT
EL. 427 m

Scale: B 10

Scale: A 30

All dimensions are

BRITIS

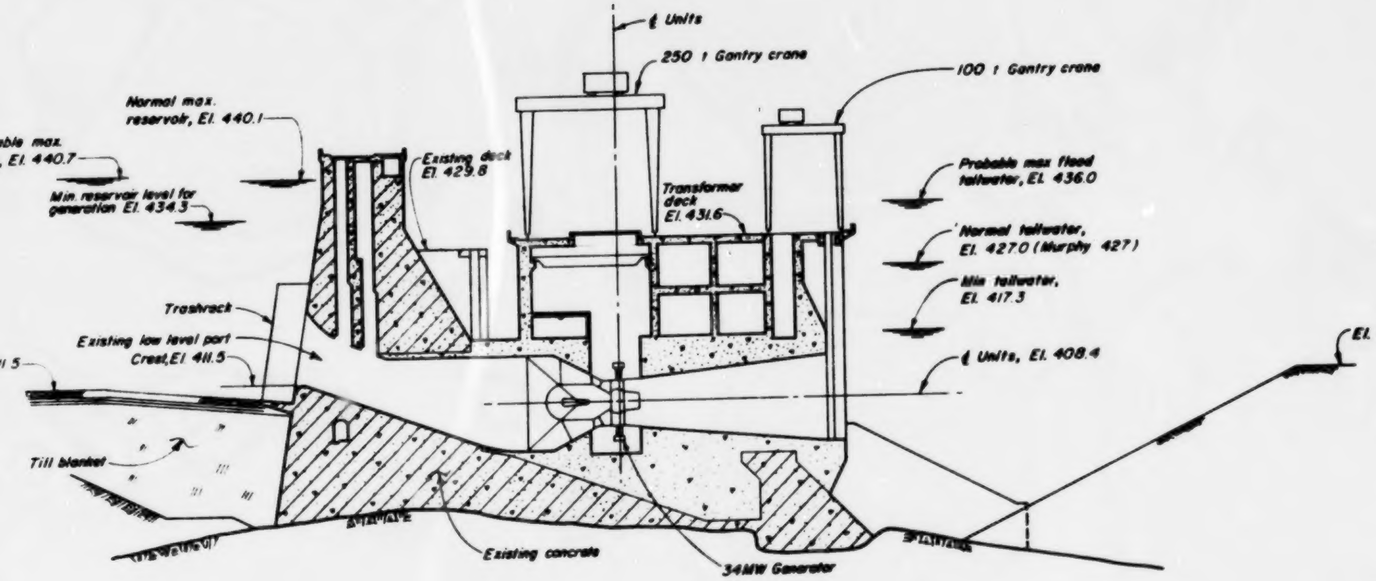
KEENLEYSI

ALTERNA
PLAN &

DATE
MAY

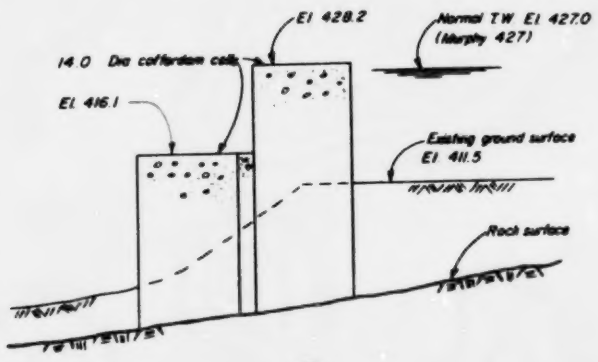
DWN
DBG

REPORT No HIG


℄ Units
250 t Gantry crane
100 t Gantry crane
Normal max. reservoir, El. 440.1
able max. , El. 440.7
Min. reservoir level for generation El. 434.3
Existing deck El. 429.8
Transformer deck El. 431.6
Probable max flood tailwater, El. 436.0
Normal tailwater, El. 427.0 (Murphy 427)
Min tailwater, El. 417.3
Trashrack
Existing low level port Crest, El 411.5
℄ Units, El. 408.4
El. 411.5
11.5
Till blanket
Existing concrete
34MW Generator

SECTION THROUGH POWERPLANT

Scale B


El 428.2
Normal T.W. El. 427.0 (Murphy 427)
14.0 Dia cofferdam cells
El. 416.1
Existing ground surface El. 411.5
Rock surface

SECTION Ⓐ

Scale B

NOTES:

1. ARRANGEMENT SHOWN IS FOR 2-34 MW UNITS WITH MURPHY HEADPOND EL. 427 m (DRAWING TAKEN FROM PREFEASIBILITY REPORT NO. H1374).

Scale: B 10 0 10 20 30 Metres

Scale: A 30 0 30 60 90 Metres

All dimensions are in metres, unless otherwise shown

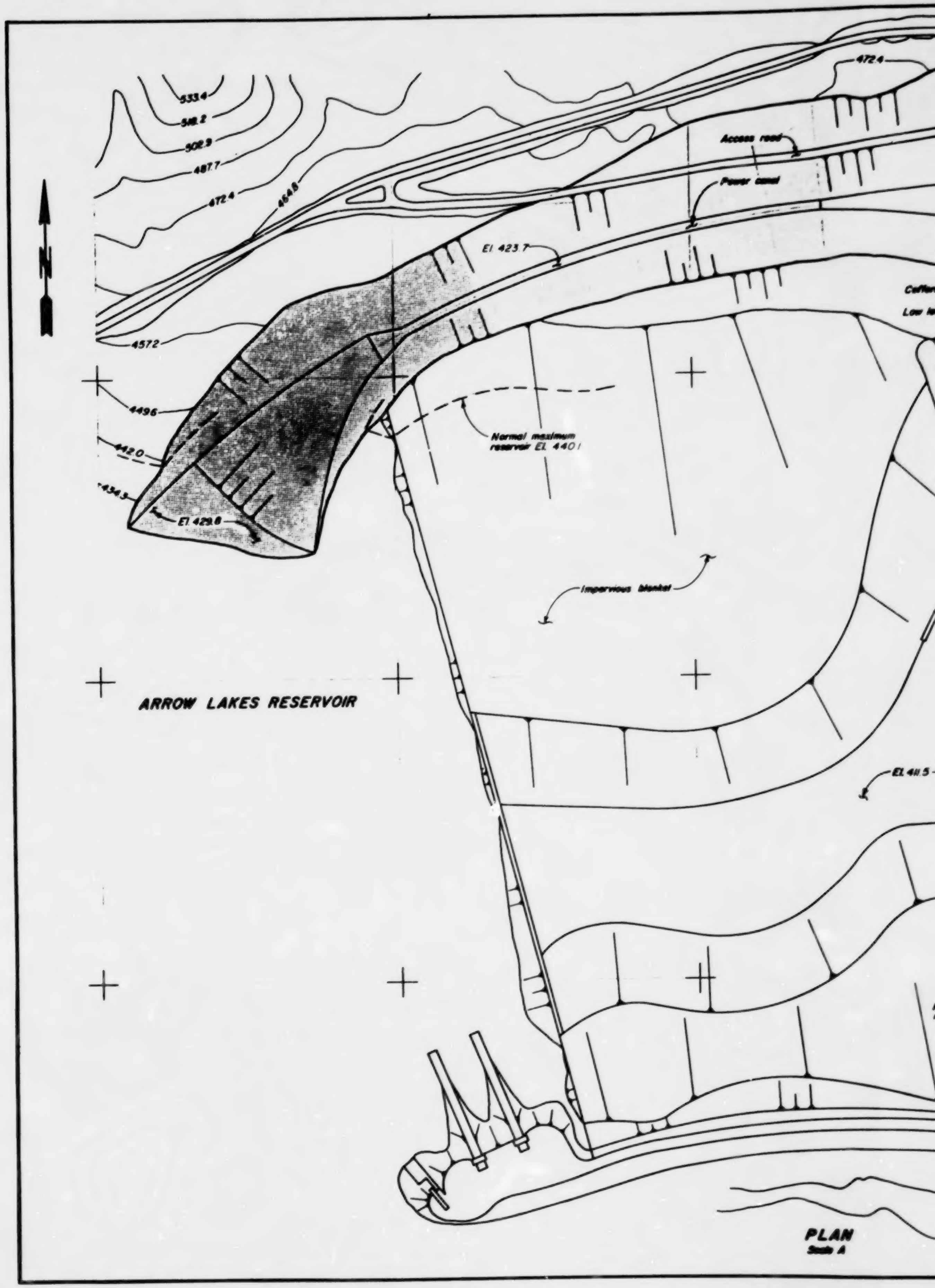
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

ALTERNATIVE I (PORT ARRANGEMENT)
PLAN & SECTIONS

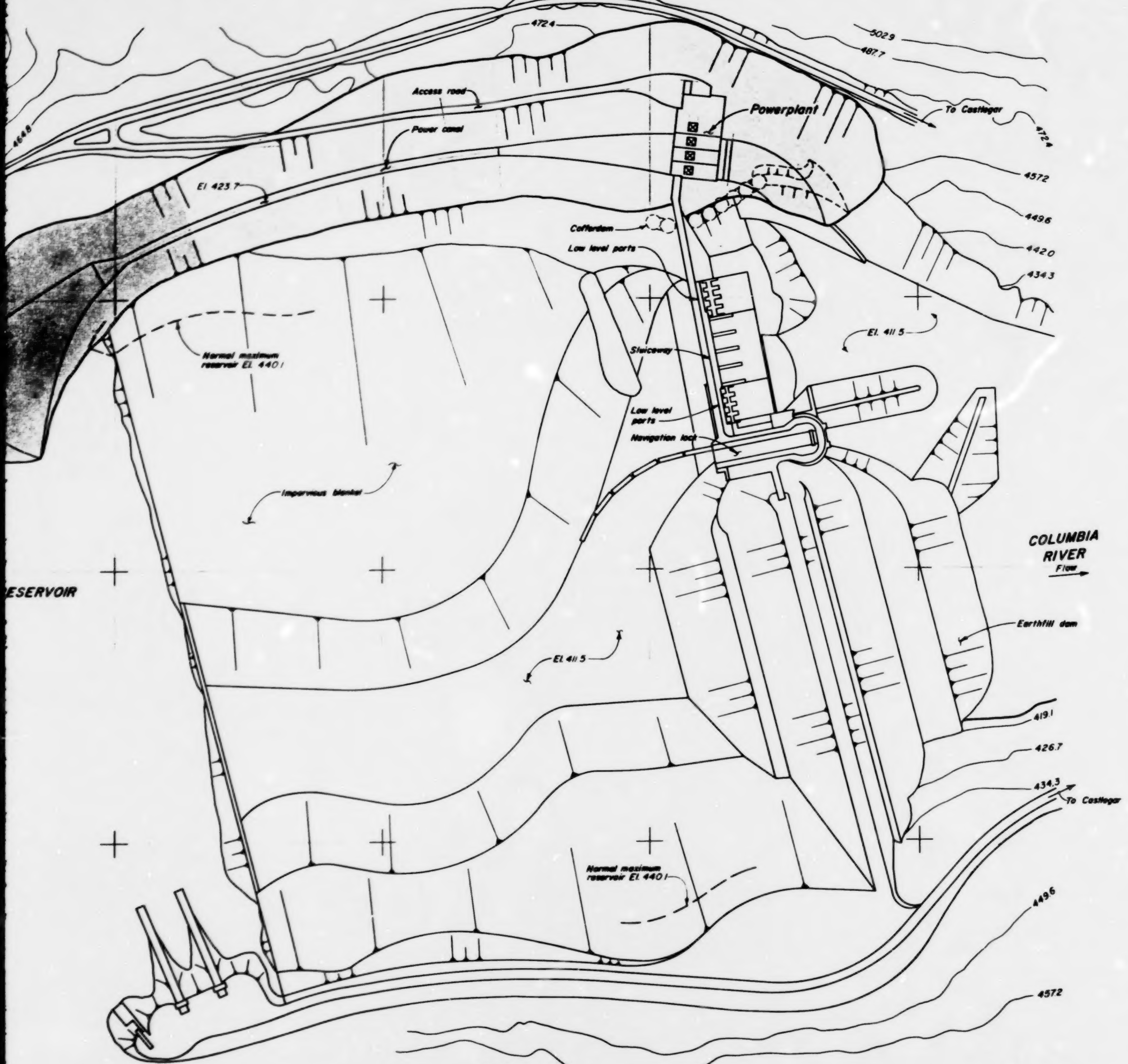
DATE MAY 1983	FIG. 6-1
DWN DBG	DWG No 240-C14-U289

REPORT No. H1613

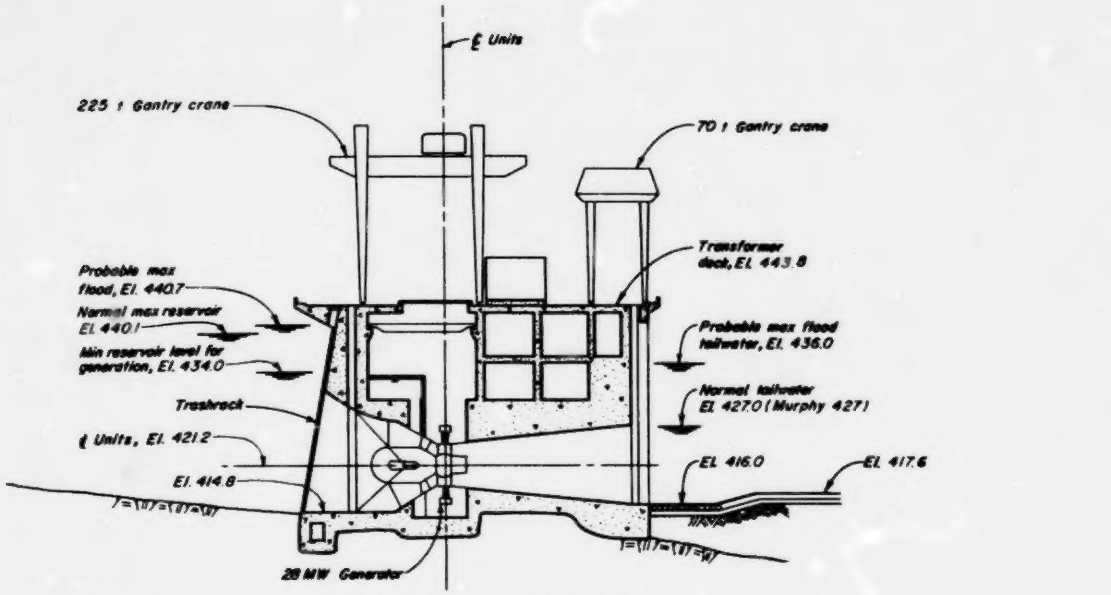

N
533.4
518.2
502.9
487.7
472.4
464.8
457.2
449.6
442.0
434.3
472.4
Access road
Power canal
El. 423.7
El. 429.8
Normal maximum reservoir El. 440.1
Impervious blanket
Coffer
Low le
ARROW LAKES RESERVOIR
El 411.5

PLAN

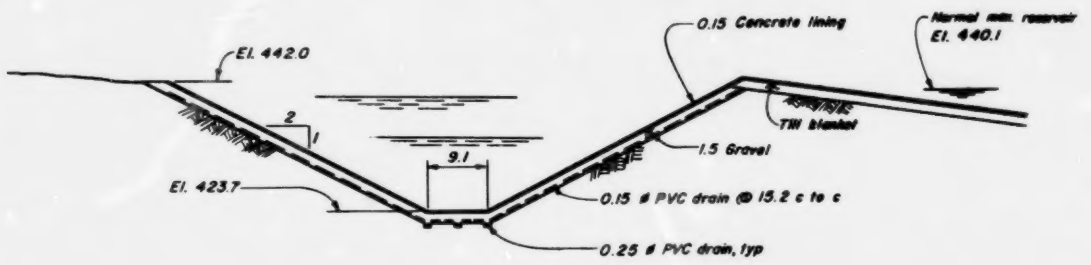
Scale A


4724
5029
487.7
4648
Access road
Power canal
Powerplant
To Castlegar
4724
4572
4496
4420
4343
El. 423.7
Cofferdam
Low level ports
Normal maximum reservoir El. 440.1
El. 411.5
Sluiceway
Low level ports
Navigation lock
Impervious blanket
ESERVOIR
COLUMBIA RIVER
Flow
Earthfill dam
El. 411.5
419.1
426.7
434.3
To Castlegar
Normal maximum reservoir El. 440.1
4496
4572

PLAN
Scale A


℄ Units
225 t Gantry crane
70 t Gantry crane
Transformer deck, El. 443.8
Probable max flood, El. 440.7
Normal max reservoir El. 440.1
Min reservoir level for generation, El. 434.0
Probable max flood tailwater, El. 436.0
Normal tailwater El. 427.0 (Murphy 427)
Trashrack
℄ Units, El. 421.2
El. 414.8
El. 416.0
El. 417.6
28 MW Generator

SECTION THROUGH POWERPLANT
Scale B


El. 442.0
0.15 Concrete lining
Normal max. reservoir El. 440.1
2
1
9.1
Till blanket
1.5 Gravel
El. 423.7
0.15 ø PVC drain @ 15.2 c to c
0.25 ø PVC drain, typ

SECTION THROUGH CANAL
Scale B

Scale: B 10 0 10 20 30 Metres

Scale: A 30 0 30 60 90 Metres

All dimensions are in metres, unless otherwise shown

NOTES:

1. ARRANGEMENT SHOWN IS FOR 3-28 MW UNITS WITH MURPHY HEADPOND EL. 427 m (DRAWING TAKEN FROM PREFEASIBILITY REPORT NO. H1374).

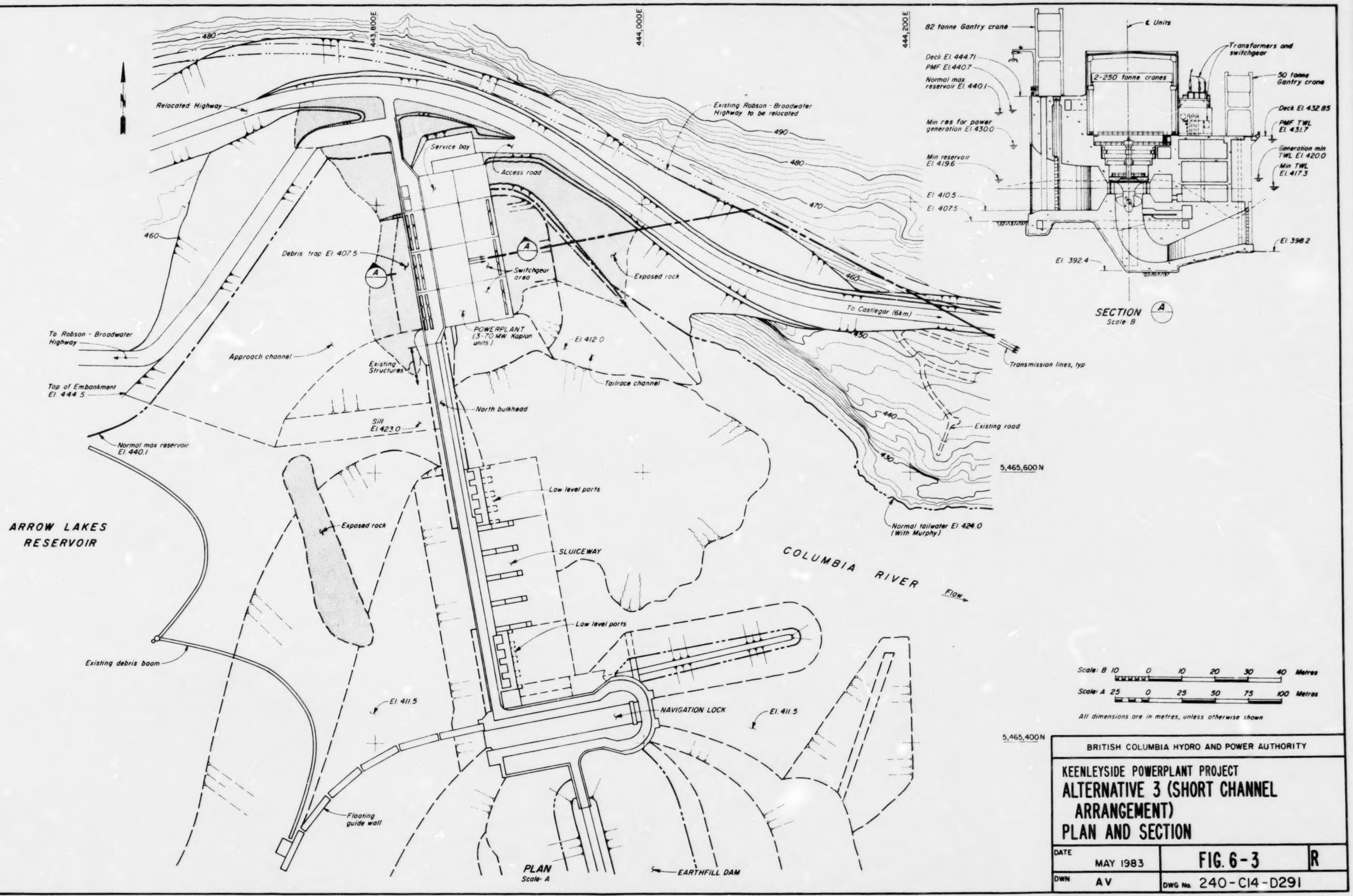
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

ALTERNATIVE 2 (CANAL ARRANGEMENT)
PLAN & SECTIONS

DATE MAY 1983	FIG. 6-2
DWN DBG	DWG No. 240-C14-U290

REPORT No. H1613


443,800E
444,000E
444,200E
480
490
480
470
460
460
450
440
430
Relocated Highway
Existing Robson - Broadwater Highway to be relocated
Service bay
Access road
Debris trap El 407.5
A
A
Switchgear area
Exposed rock
To Castlegar (6km)
To Robson - Broadwater Highway
Approach channel
POWERPLANT (3-70 MW Kaplan units)
El 412.0
Existing Structures
Tailrace channel
Transmission lines, typ
Top of Embankment El 444.5
North bulkhead
Existing road
Sill El 423.0
Normal max reservoir El 440.1
5,465,600N
Low level ports
Exposed rock
Normal tailwater El 424.0 (With Murphy)
ARROW LAKES RESERVOIR
SLUICEWAY
COLUMBIA RIVER
Flow
Low level ports
Existing debris boom
El 411.5
NAVIGATION LOCK
El 411.5
Floating guide wall
PLAN
Scale: A
EARTHFILL DAM
82 tonne Gantry crane
℄ Units
Transformers and switchgear
Deck El 444.71
PMF El 440.7
Normal max reservoir El 440.1
2-250 tonne cranes
50 tonne Gantry crane
Deck El 432.85
PMF TWL El 431.7
Min res for power generation El 430.0
Generation min TWL El 420.0
Min reservoir El 419.6
Min TWL El 417.3
El 410.5
El 407.5
El 398.2
El 392.4
SECTION A
Scale B
Scale: B 10 0 10 20 30 40 Metres
Scale: A 25 0 25 50 75 100 Metres

All dimensions are in metres, unless otherwise shown

5,465,400N

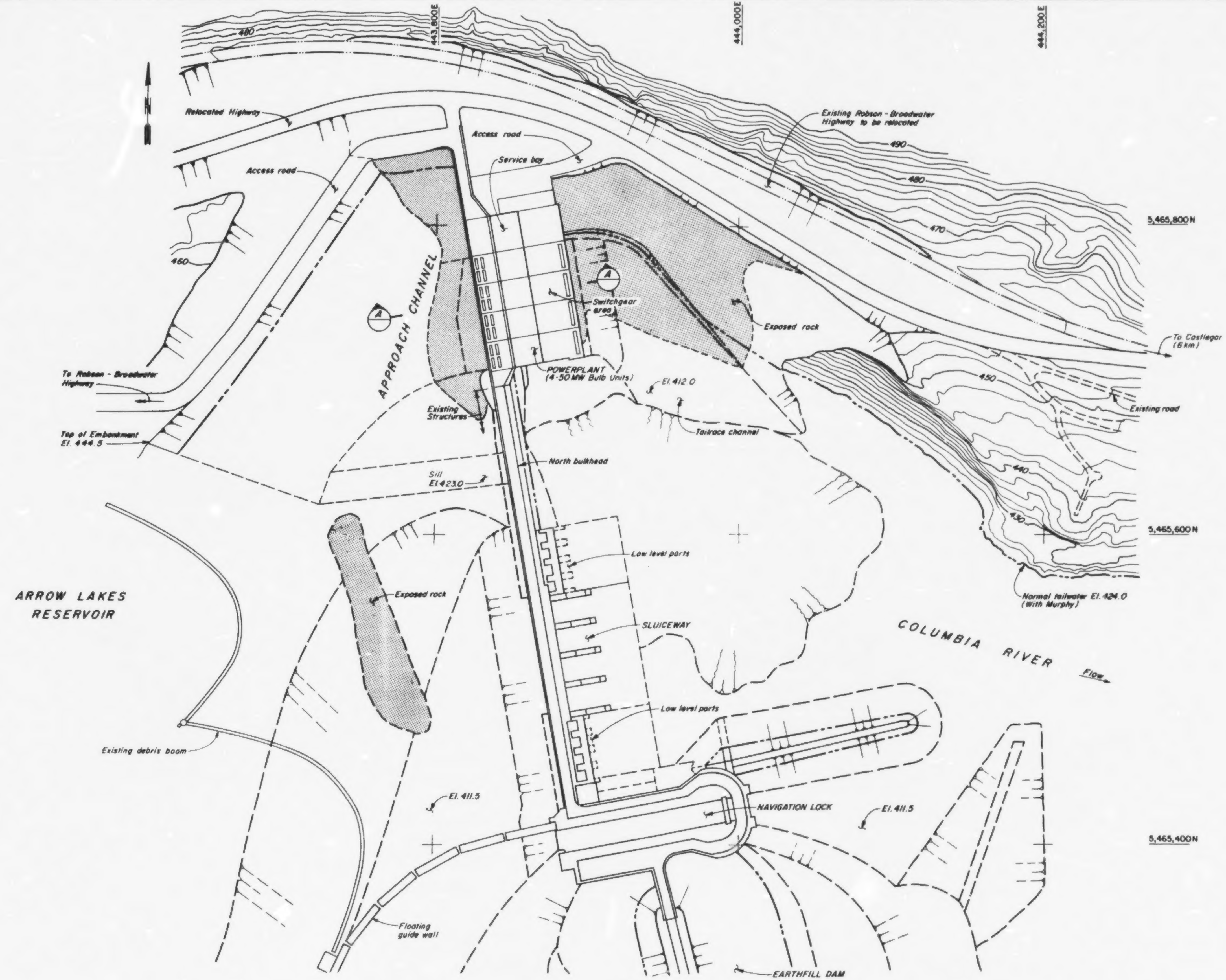
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

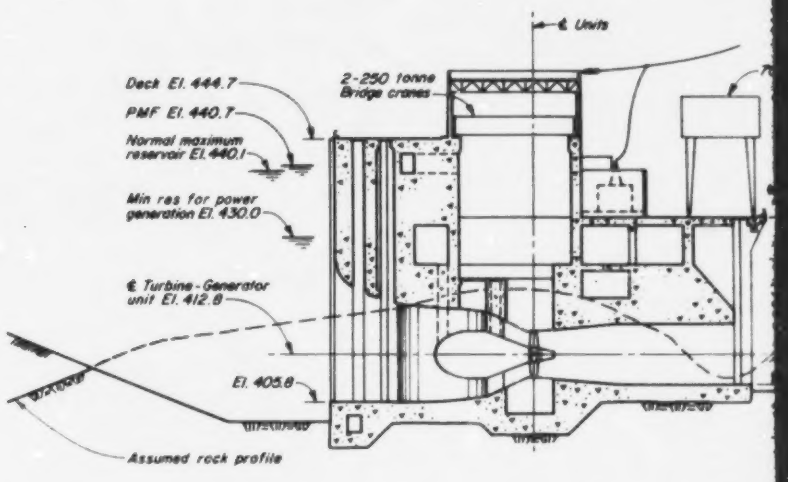
ALTERNATIVE 3 (SHORT CHANNEL ARRANGEMENT)
PLAN AND SECTION

DATE MAY 1983	FIG. 6-3	R
DWN AV	DWG No. 240-C14-D291	

REPORT No. H1613


443,800E
444,000E
444,200E
N
480
490
480
470
460
450
440
430
Relocated Highway
Existing Robson - Broadwater Highway to be relocated
Access road
Access road
Service bay
5,465,800N
5,465,600N
5,465,400N
APPROACH CHANNEL
A
A
Switchgear area
Exposed rock
To Castlegar (6 km)
To Robson - Broadwater Highway
POWERPLANT (4-50 MW Bulb Units)
El. 412.0
Existing road
Existing Structures
Top of Embankment El. 444.5
Tailrace channel
North bulkhead
Sill El. 423.0
Low level ports
Normal tailwater El. 424.0 (With Murphy)
ARROW LAKES RESERVOIR
Exposed rock
SLUICEWAY
COLUMBIA RIVER
Flow
Low level ports
Existing debris boom
El. 411.5
NAVIGATION LOCK
El. 411.5
Floating guide wall
EARTHFILL DAM

PLAN
Scale A


℄ Units
Deck El. 444.7
2-250 tonne Bridge cranes
PMF El. 440.7
Normal maximum reservoir El. 440.1
Min res for power generation El. 430.0
℄ Turbine - Generator unit El. 412.8
El. 405.8
Assumed rock profile

SECTION A
Scale B

Scale: B 10 0

Scale: A 25 0

All dimensions are in

BRITISH COLUM

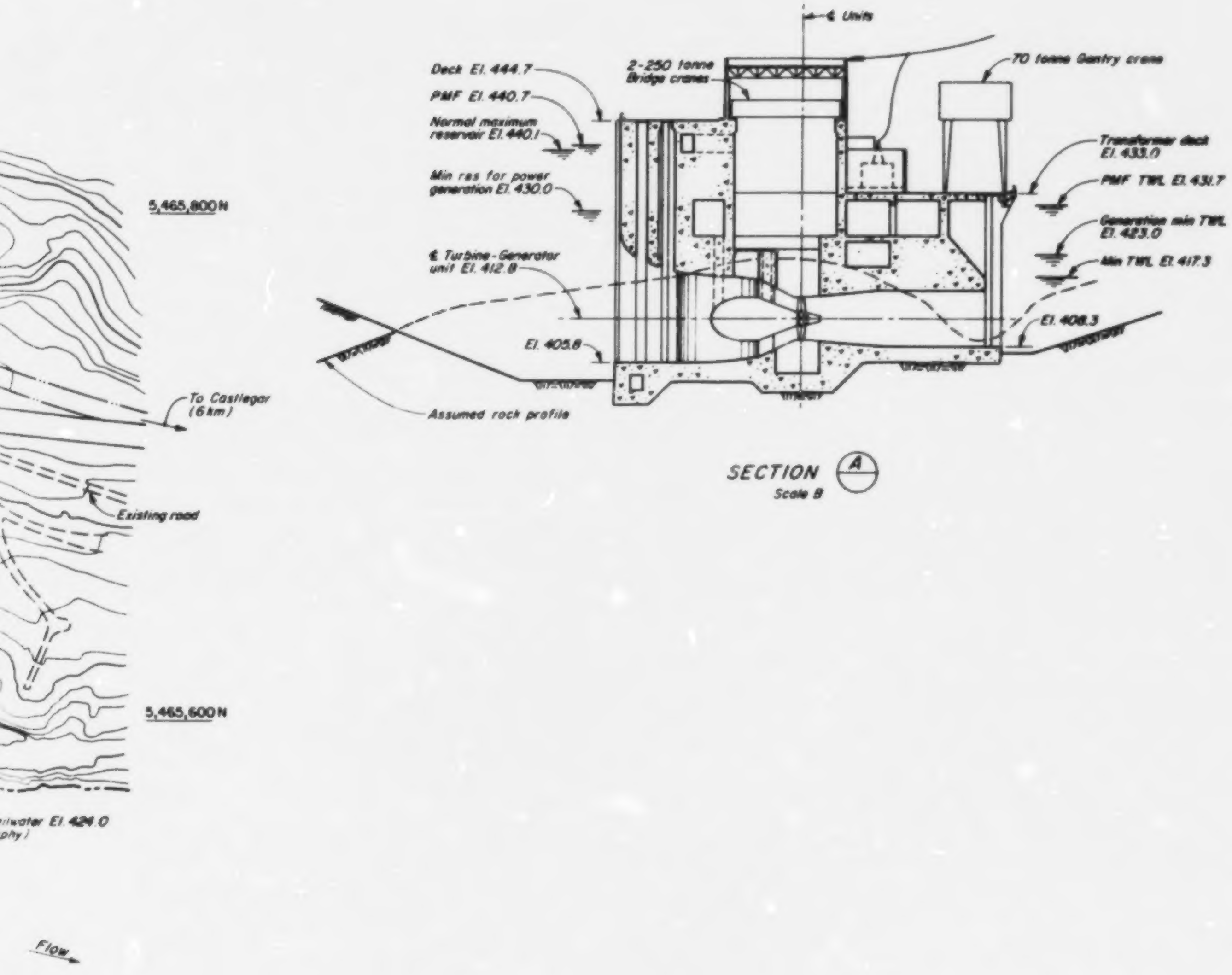
KEENLEYSIDE POWE

ALTERNATIVE

PLAN & SECT

DATE	MAY 1983
DWN	A.V.

REPORT No H1613


5,465,800 N
5,465,600 N
To Castlegar (6 km)
Existing road
ilwater El. 424.0
phy)
Flow
℄ Units
Deck El. 444.7
PMF El. 440.7
Normal maximum reservoir El. 440.1
Min res for power generation El. 430.0
℄ Turbine-Generator unit El. 412.8
El. 405.8
Assumed rock profile
2-250 tonne Bridge cranes
70 tonne Gantry crane
Transformer deck El. 433.0
PMF TWL El. 431.7
Generation min TWL El. 423.0
Min TWL El. 417.3
El. 408.3
SECTION A
Scale B

5,465,400 N

Scale: B 10 0 10 20 30 40 Metres

Scale: A 25 0 25 50 75 100 Metres

All dimensions are in metres, unless otherwise shown

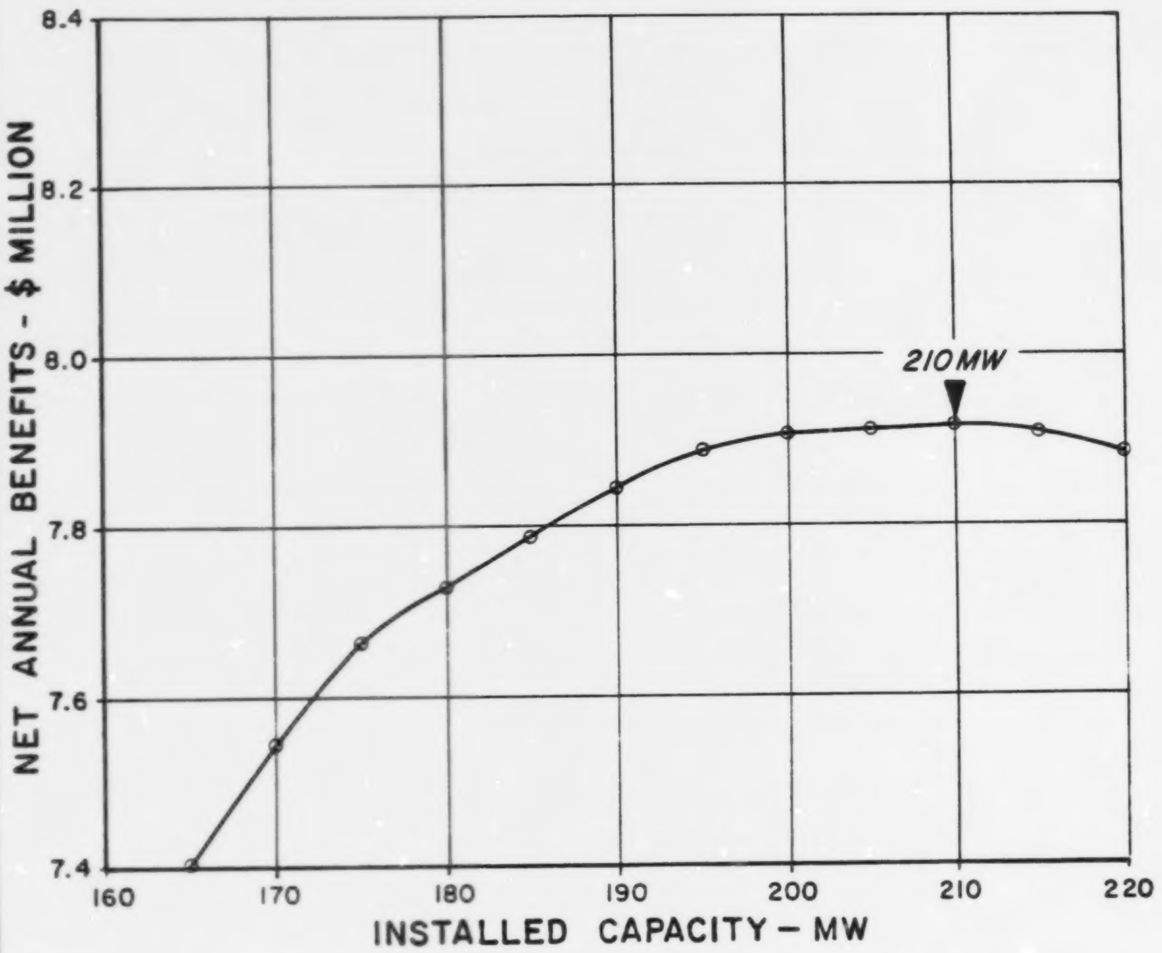
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

ALTERNATIVE BULB UNIT ARRANGEMENT
PLAN & SECTION

DATE MAY 1983	FIG. 6-4
DWN A.V.	DWG No. 240-C14-U292

REPORT No H1613



N O T E S:

1. NET BENEFITS ARE BASED ON OCTOBER 1981 PRICE LEVELS.
2. ANNUAL WATER FEES AND PROPERTY TAXES HAVE NOT BEEN INCLUDED IN THE ANNUAL COSTS.
3. COSTS BASED ON SHORT CHANNEL ARRANGEMENT WITH KAPLAN TURBINES.

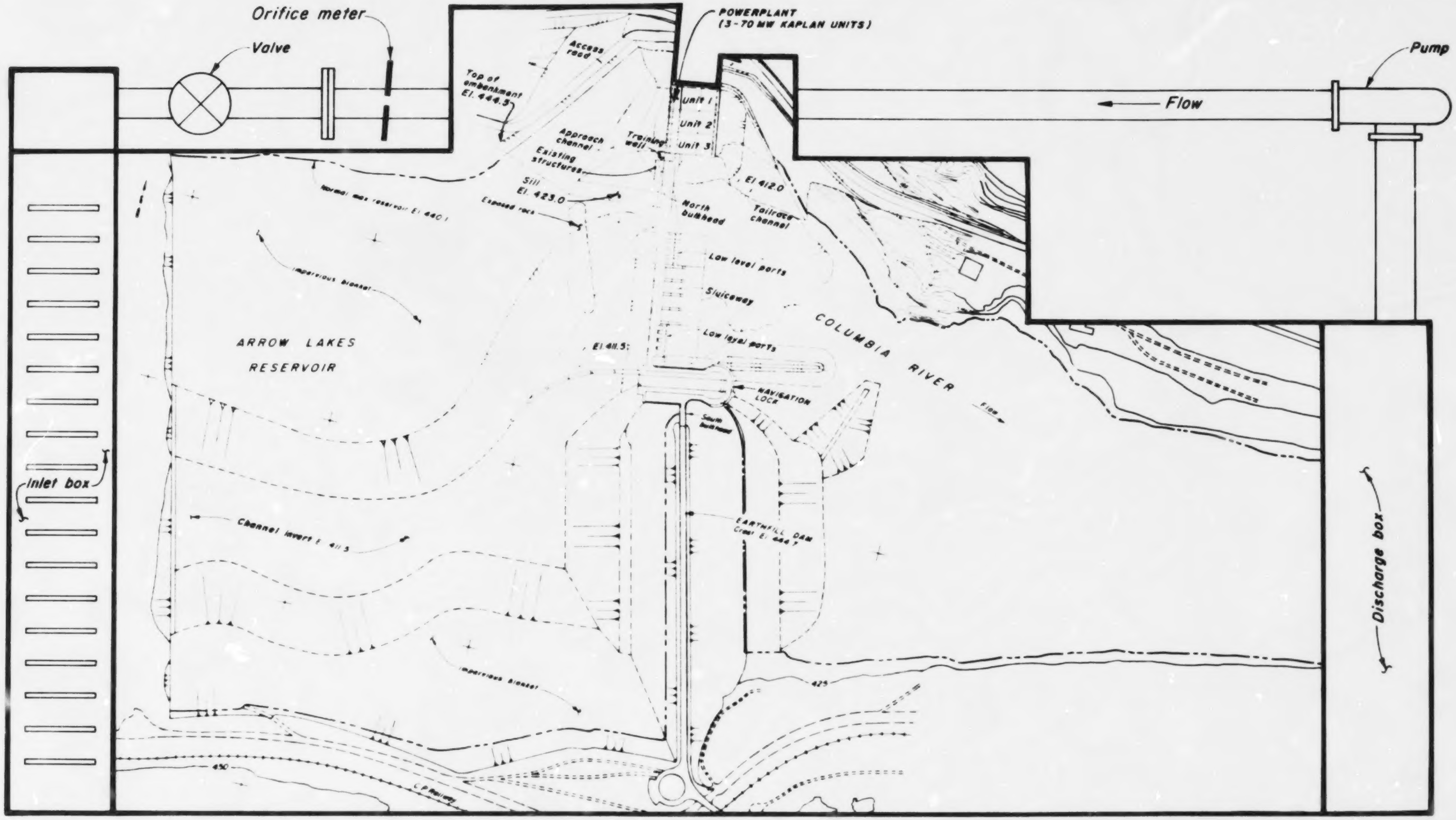
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWEPLANT PROJECT

CAPACITY OPTIMIZATION

DATE MAY '83	FIG 6-5
DWN AH	DWG No 240-C14-A293

REPORT No H1613


Orifice meter
Valve
POWERPLANT (3-70 MW KAPLAN UNITS)
Pump
Flow
Access road
Top of embankment El. 444.5
Approach channel
Existing structures
Training wall
Unit 1
Unit 2
Unit 3
Sill El. 423.0
Exposed rock
Normal max reservoir El 440.1
El 412.0
North bulkhead
Tailrace channel
Low level ports
Sluiceway
Low level ports
Impervious blanket
ARROW LAKES RESERVOIR
El 411.5
COLUMBIA RIVER
Flow
NAVIGATION LOCK
South bulkhead
Inlet box
Channel invert El 411.3
EARTHFILL DAM Crest El 444.7
Discharge box
Impervious blanket
425
450
C.P. Railway

Scale: 100 0 100 200 Metres

NOTE: MODEL SCALE 1:100

All dimensions are in metres, unless otherwise shown

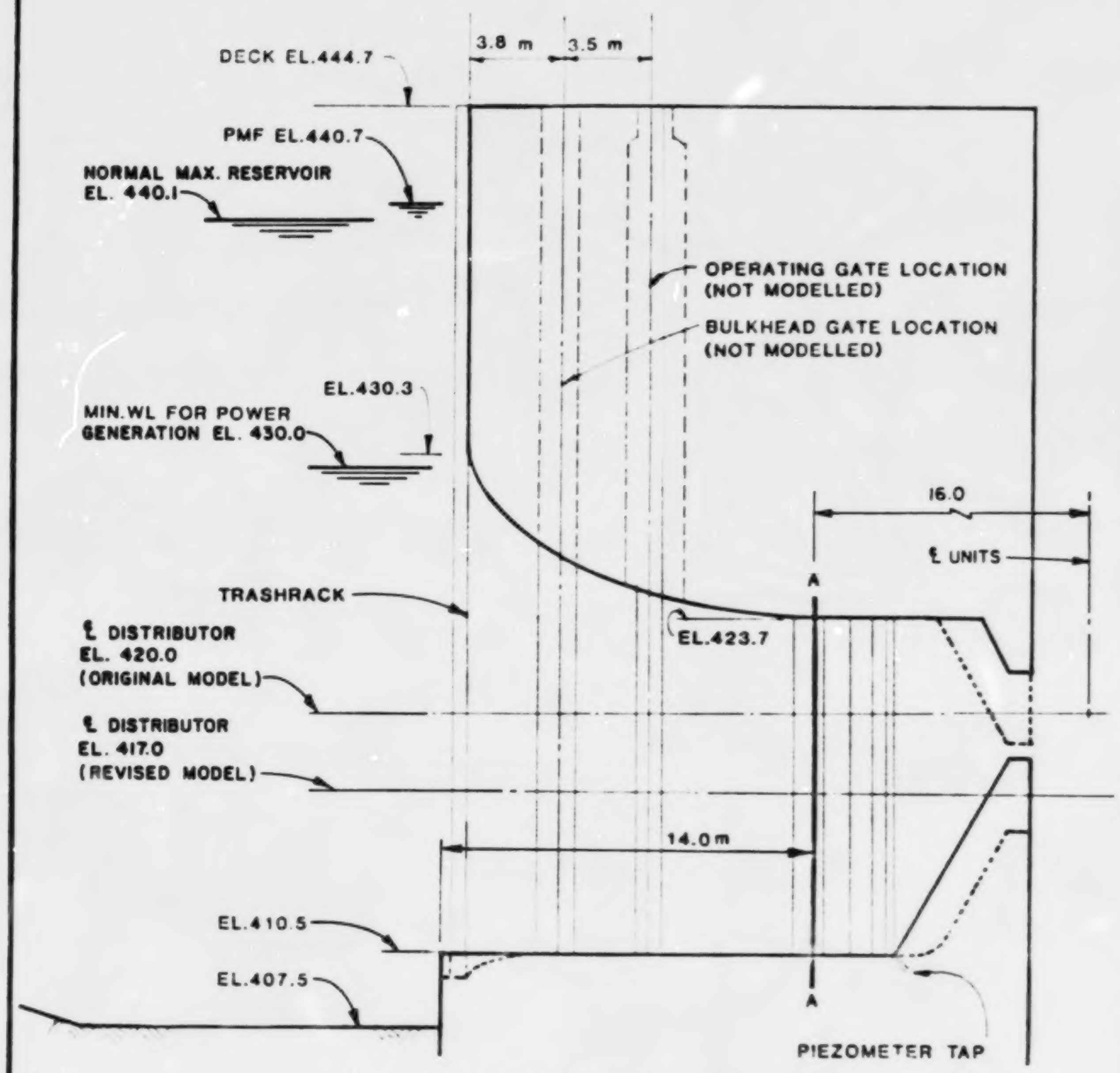
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

HYDRAULIC MODEL
GENERAL ARRANGEMENT

DATE MAY 1983	FIG. 7-1
DWN SM	DWG No 240-C14-B294

REPORT No H1613


DECK EL.444.7
3.8 m
3.5 m
PMF EL.440.7
NORMAL MAX. RESERVOIR EL. 440.1
OPERATING GATE LOCATION (NOT MODELLED)
BULKHEAD GATE LOCATION (NOT MODELLED)
EL.430.3
MIN.WL FOR POWER GENERATION EL. 430.0
16.0
℄ UNITS
A
TRASHRACK
EL.423.7
℄ DISTRIBUTOR EL. 420.0 (ORIGINAL MODEL)
℄ DISTRIBUTOR EL. 417.0 (REVISED MODEL)
14.0m
EL.410.5
EL.407.5
A
PIEZOMETER TAP

All dimensions are in metres, unless otherwise shown

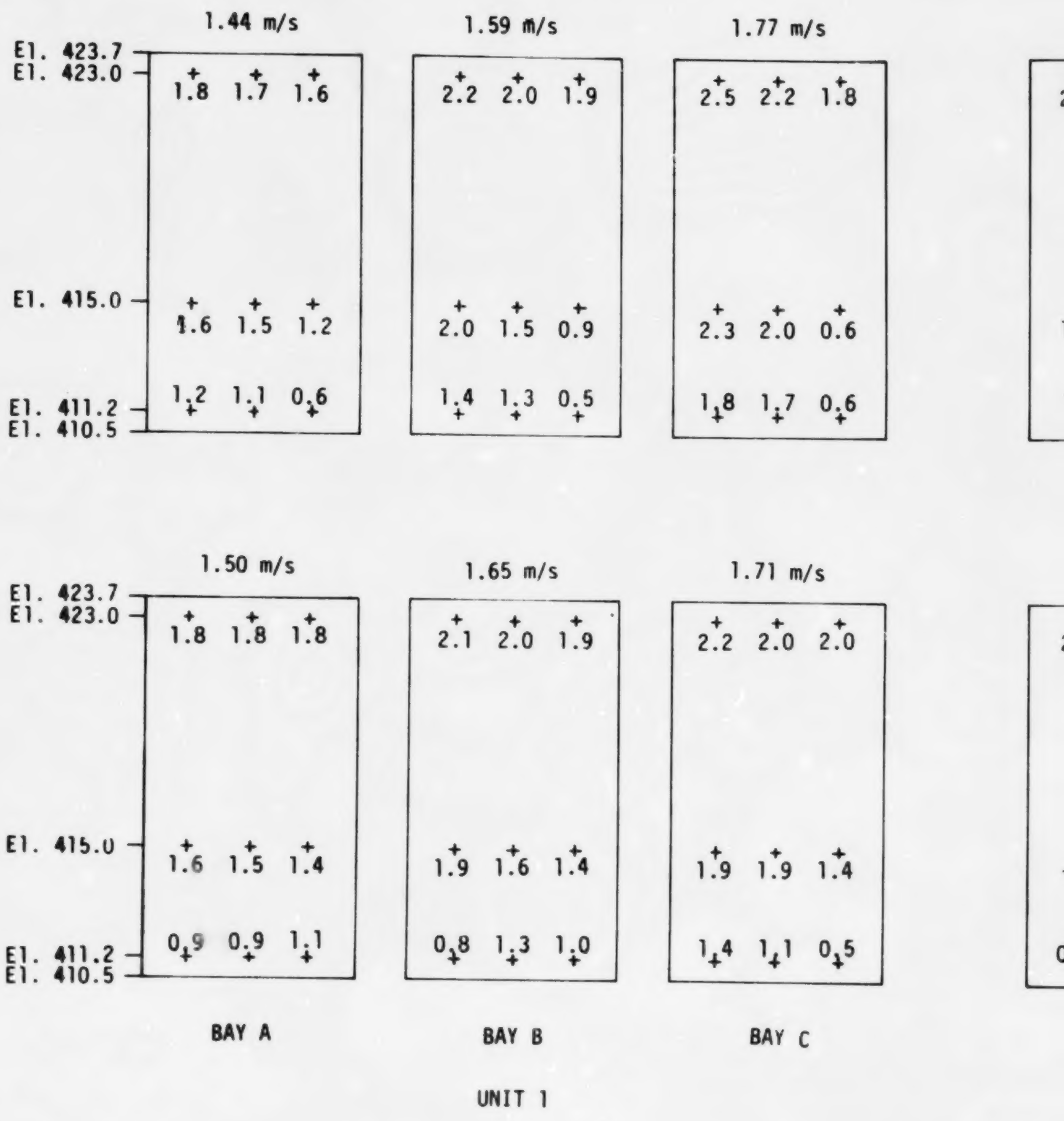
NOTES 1. STAY RING OPENING MODELLED AS A TWO-DIMENSIONAL SLOT AS SHOWN

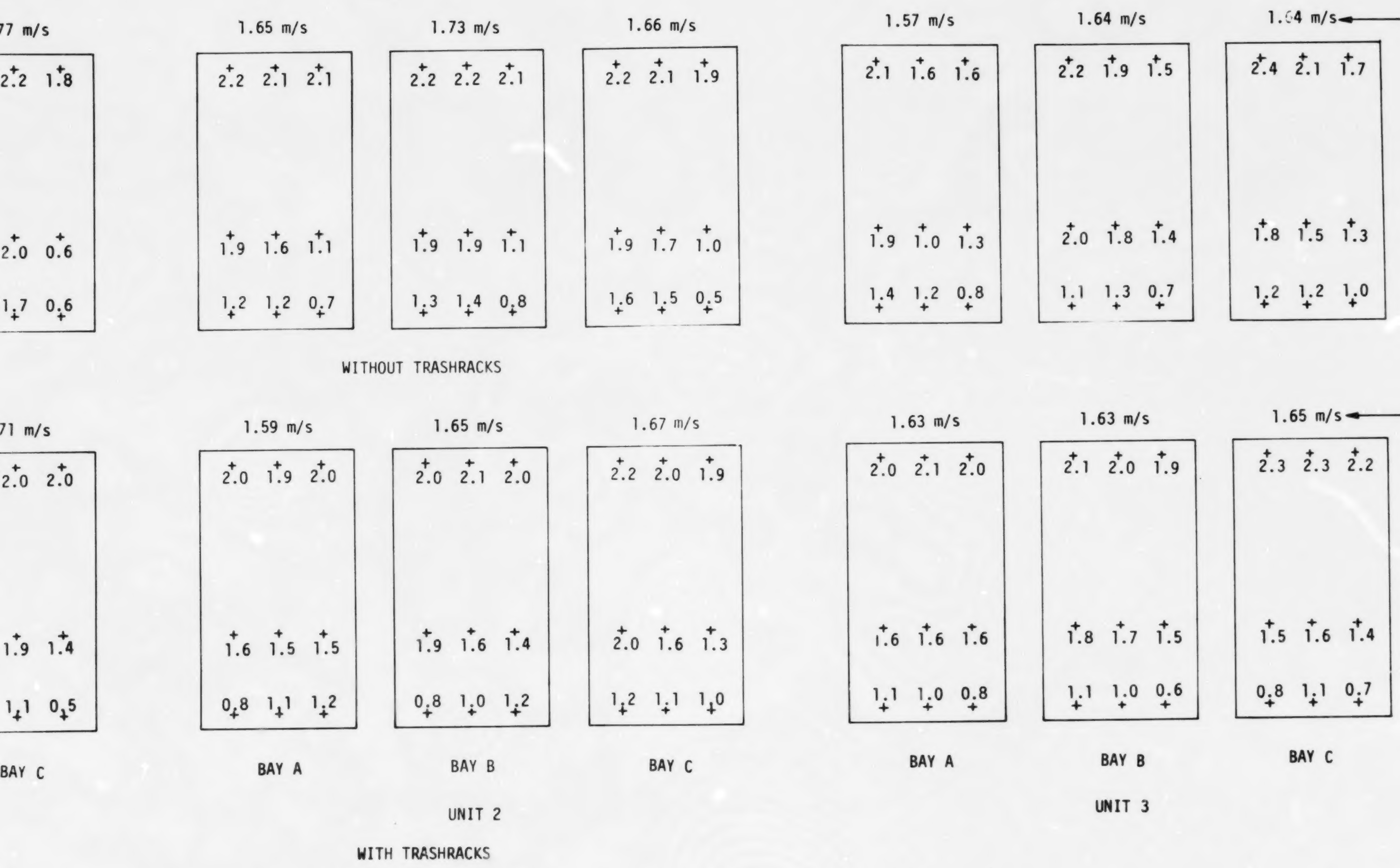
2. ———— MODEL PROFILE FOR LOWER DISTRIBUTOR

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY
KEENLEYSIDE POWERPLANT PROJECT
HYDRAULIC MODEL
INTAKE SECTION

DATE MAY 1983
FIG. 7-2
DWN
DWG. No. 240-C14-A295

REPORT No. H1613


1.44 m/s
1.59 m/s
1.77 m/s
El. 423.7
El. 423.0
1.8 1.7 1.6
2.2 2.0 1.9
2.5 2.2 1.8
El. 415.0
1.6 1.5 1.2
2.0 1.5 0.9
2.3 2.0 0.6
El. 411.2
El. 410.5
1.2 1.1 0.6
1.4 1.3 0.5
1.8 1.7 0.6
1.50 m/s
1.65 m/s
1.71 m/s
El. 423.7
El. 423.0
1.8 1.8 1.8
2.1 2.0 1.9
2.2 2.0 2.0
El. 415.0
1.6 1.5 1.4
1.9 1.6 1.4
1.9 1.9 1.4
El. 411.2
El. 410.5
0.9 0.9 1.1
0.8 1.3 1.0
1.4 1.1 0.5
BAY A
BAY B
BAY C
UNIT 1


77 m/s
2.2 1.8
2.0 0.6
1.7 0.6
1.65 m/s
2.2 2.1 2.1
1.9 1.6 1.1
1.2 1.2 0.7
1.73 m/s
2.2 2.2 2.1
1.9 1.9 1.1
1.3 1.4 0.8
1.66 m/s
2.2 2.1 1.9
1.9 1.7 1.0
1.6 1.5 0.5
1.57 m/s
2.1 1.6 1.6
1.9 1.0 1.3
1.4 1.2 0.8
1.64 m/s
2.2 1.9 1.5
2.0 1.8 1.4
1.1 1.3 0.7
1.64 m/s
2.4 2.1 1.7
1.8 1.5 1.3
1.2 1.2 1.0
WEIGHTED AVERAGE BAY VELOCITY
WITHOUT TRASHRACKS
71 m/s
2.0 2.0
1.9 1.4
1.1 0.5
1.59 m/s
2.0 1.9 2.0
1.6 1.5 1.5
0.8 1.1 1.2
1.65 m/s
2.0 2.1 2.0
1.9 1.6 1.4
0.8 1.0 1.2
1.67 m/s
2.2 2.0 1.9
2.0 1.6 1.3
1.2 1.1 1.0
1.63 m/s
2.0 2.1 2.0
1.6 1.6 1.6
1.1 1.0 0.8
1.63 m/s
2.1 2.0 1.9
1.8 1.7 1.5
1.1 1.0 0.6
1.65 m/s
2.3 2.3 2.2
1.5 1.6 1.4
0.8 1.1 0.7
WEIGHTED AVERAGE BAY VELOCITY
BAY C
BAY A
BAY B
BAY C
BAY A
BAY B
BAY C
UNIT 2
UNIT 3
WITH TRASHRACKS

RESERVOIR AT EL. 430 m
DISCHARGE - 460 m^3/s PER UNIT
AVERAGE VELOCITY - Q/A - 1.63 m/s
AVERAGE VELOCITY, LEFT SIDES - 1.91 m/s
AVERAGE VELOCITY, RIGHT SIDES - 1.27 m/2
LEFT/RIGHT VELOCITY RATIO - 1.51

RESERVOIR AT EL. 430 m
DISCHARGE - 460 m^3/s PER UNIT
AVERAGE VELOCITY - Q/A - 1.63 m /s
AVERAGE VELOCITY, LEFT SIDES - 1.72 m/s
AVERAGE VELOCITY, RIGHT SIDES - 1.52 m/s
LEFT/RIGHT VELOCITY RATIO - 1.13

NOTES:

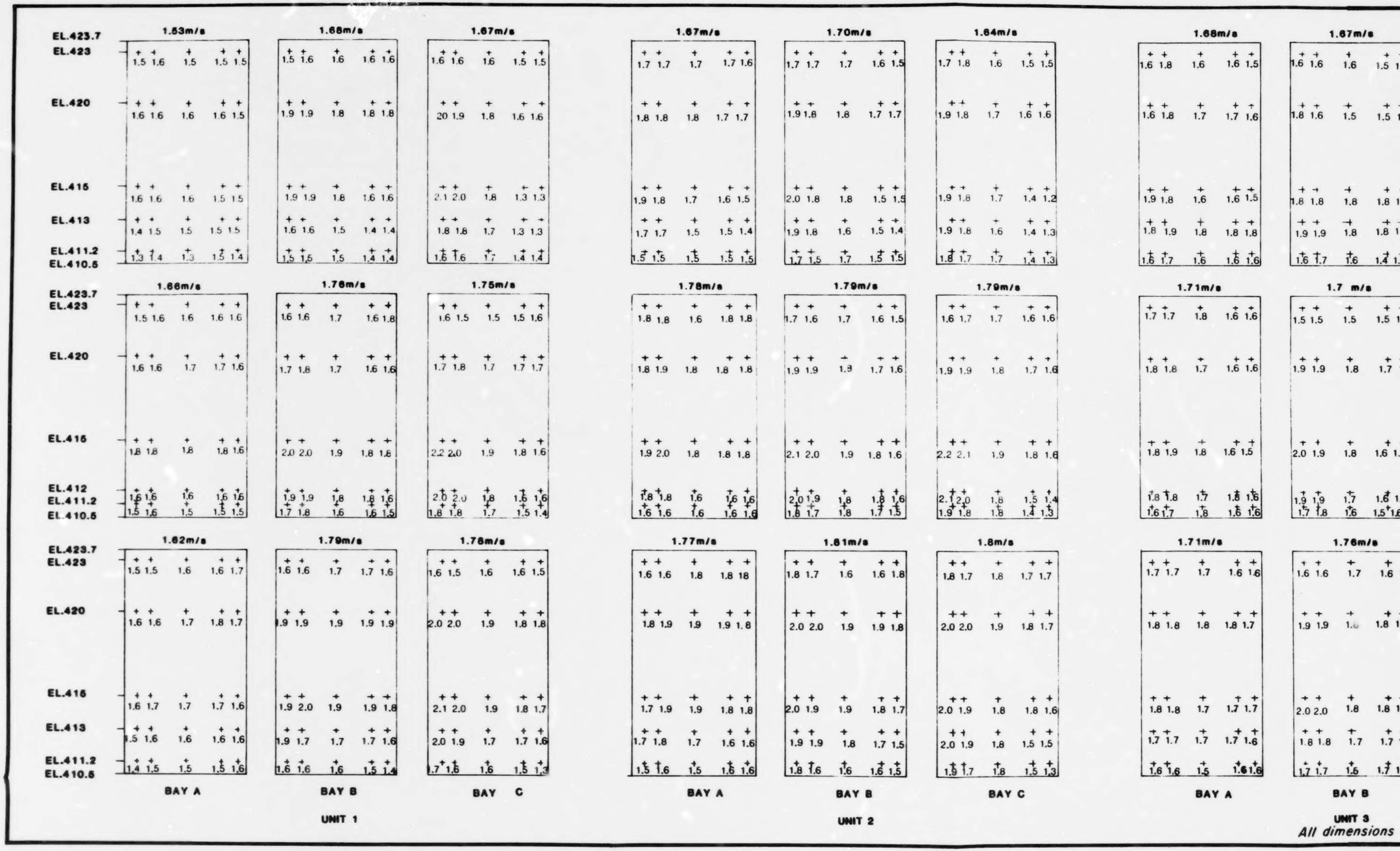
1. VELOCITIES MEASURED AT SECTION A-A (FIG. 7-2).
2. CENTRELINE DISTRIBUTOR AT EL. 420 m.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

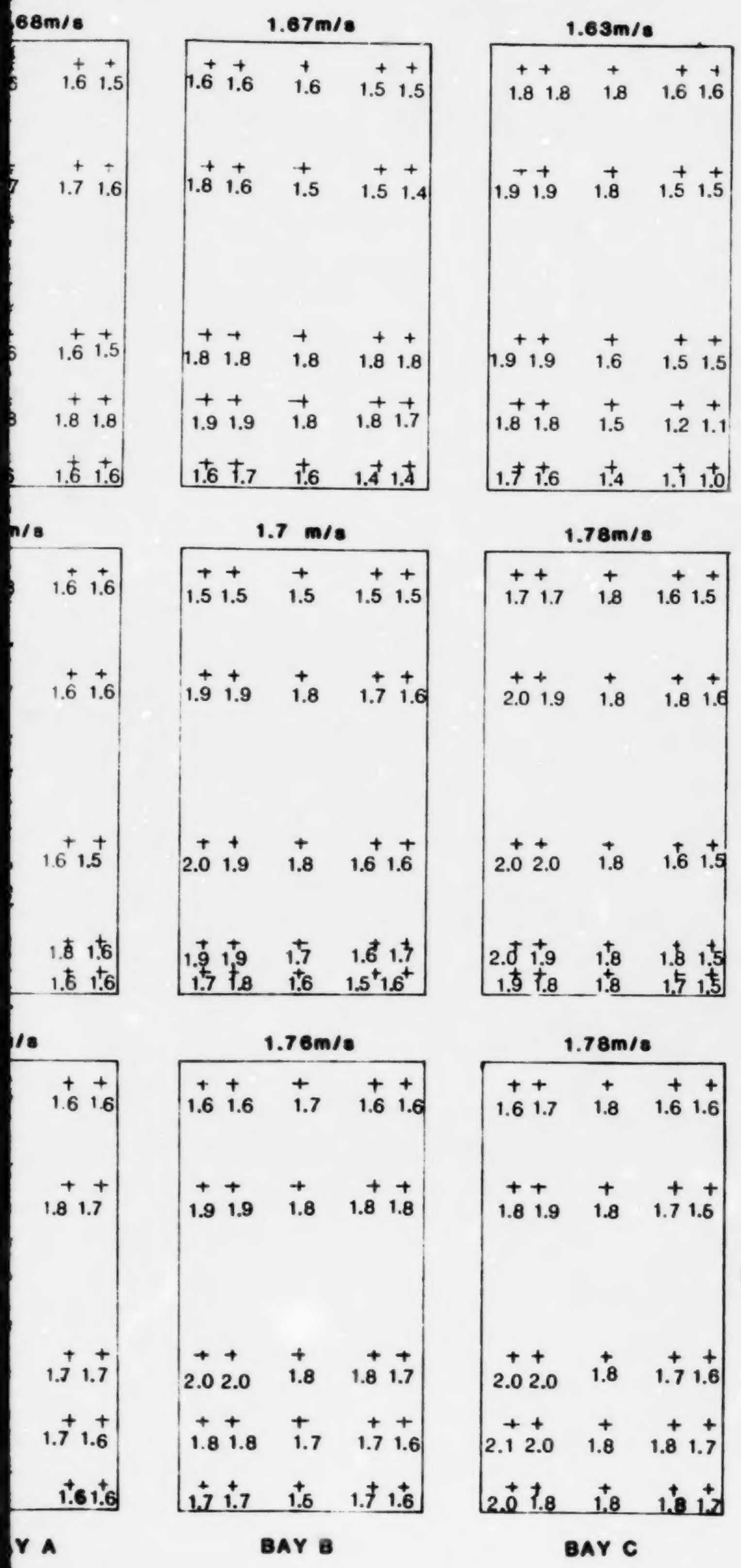
KEENLEYSIDE POWERPLANT PROJECT
HYDRAULIC MODEL
INTAKE VELOCITY DISTRIBUTION
EFFECT OF TRASHRACKS

All dimensions are in metres, unless otherwise shown

DATE MAY 1983
FIG. 7-3
DWN S M
DWG. No. 240 - C14 - D296
REPORT No. H1613


EL.423.7
EL.423
EL.420
EL.415
EL.413
EL.412
EL.411.2
EL.410.5
1.53m/s
1.68m/s
1.67m/s
1.67m/s
1.70m/s
1.64m/s
1.68m/s
1.67m/s
1.66m/s
1.76m/s
1.75m/s
1.78m/s
1.79m/s
1.79m/s
1.71m/s
1.7 m/s
1.62m/s
1.79m/s
1.78m/s
1.77m/s
1.81m/s
1.8m/s
1.71m/s
1.76m/s
BAY A
BAY B
BAY C
UNIT 1
UNIT 2
UNIT 3

All dimensions


68m/s
1.67m/s
1.63m/s
1.6 1.5
1.7 1.6
1.6 1.5
1.8 1.8
1.6 1.6
1.6 1.6 1.6 1.5 1.5
1.8 1.6 1.5 1.5 1.4
1.8 1.8 1.8 1.8 1.8
1.9 1.9 1.8 1.8 1.7
1.6 1.7 1.6 1.4 1.4
1.8 1.8 1.8 1.6 1.6
1.9 1.9 1.8 1.5 1.5
1.9 1.9 1.6 1.5 1.5
1.8 1.8 1.5 1.2 1.1
1.7 1.6 1.4 1.1 1.0
m/s
1.7 m/s
1.78m/s
1.6 1.6
1.6 1.6
1.6 1.5
1.8 1.6
1.6 1.6
1.5 1.5 1.5 1.5 1.5
1.9 1.9 1.8 1.7 1.6
2.0 1.9 1.8 1.6 1.6
1.9 1.9 1.7 1.6 1.7
1.7 1.8 1.6 1.5 1.6
1.7 1.7 1.8 1.6 1.5
2.0 1.9 1.8 1.8 1.6
2.0 2.0 1.8 1.6 1.5
2.0 1.9 1.8 1.8 1.5
1.9 1.8 1.8 1.7 1.5
/s
1.76m/s
1.78m/s
1.6 1.6
1.8 1.7
1.7 1.7
1.7 1.6
1.6 1.6
1.6 1.6 1.7 1.6 1.6
1.9 1.9 1.8 1.8 1.8
2.0 2.0 1.8 1.8 1.7
1.8 1.8 1.7 1.7 1.6
1.7 1.7 1.6 1.7 1.6
1.6 1.7 1.8 1.6 1.6
1.8 1.9 1.8 1.7 1.6
2.0 2.0 1.8 1.7 1.6
2.1 2.0 1.8 1.8 1.7
2.0 1.8 1.8 1.8 1.7
Y A
BAY B
BAY C
UNIT 3

WEIGHTED AVERAGE BAY VELOCITY

RESERVOIR AT EL.430m
DISCHARGE - 460m^3/s PER UNIT
AVERAGE VELOCITY - Q/A - 1.63m/s
WEIGHTED AVERAGE OF DATA - 1.65m/s

WEIGHTED AVERAGE BAY VELOCITY

RESERVOIR AT EL.435m
DISCHARGE - 500m^3/s PER UNIT
AVERAGE VELOCITY - Q/A - 1.77m/s
WEIGHTED AVERAGE OF DATA - 1.75m/s

WEIGHTED AVERAGE BAY VELOCITY

RESERVOIR AT EL.440.1m
DISCHARGE - 500 m^3/s PER UNIT
AVERAGE VELOCITY - Q/A - 1.77m/s
WEIGHTED AVERAGE OF DATA - 1.76m/s

NOTES: VELOCITIES MEASURED AT SECTION A-A (FIG. 7-2)
CENTRELINE DISTRIBUTOR AT EL. 417.0

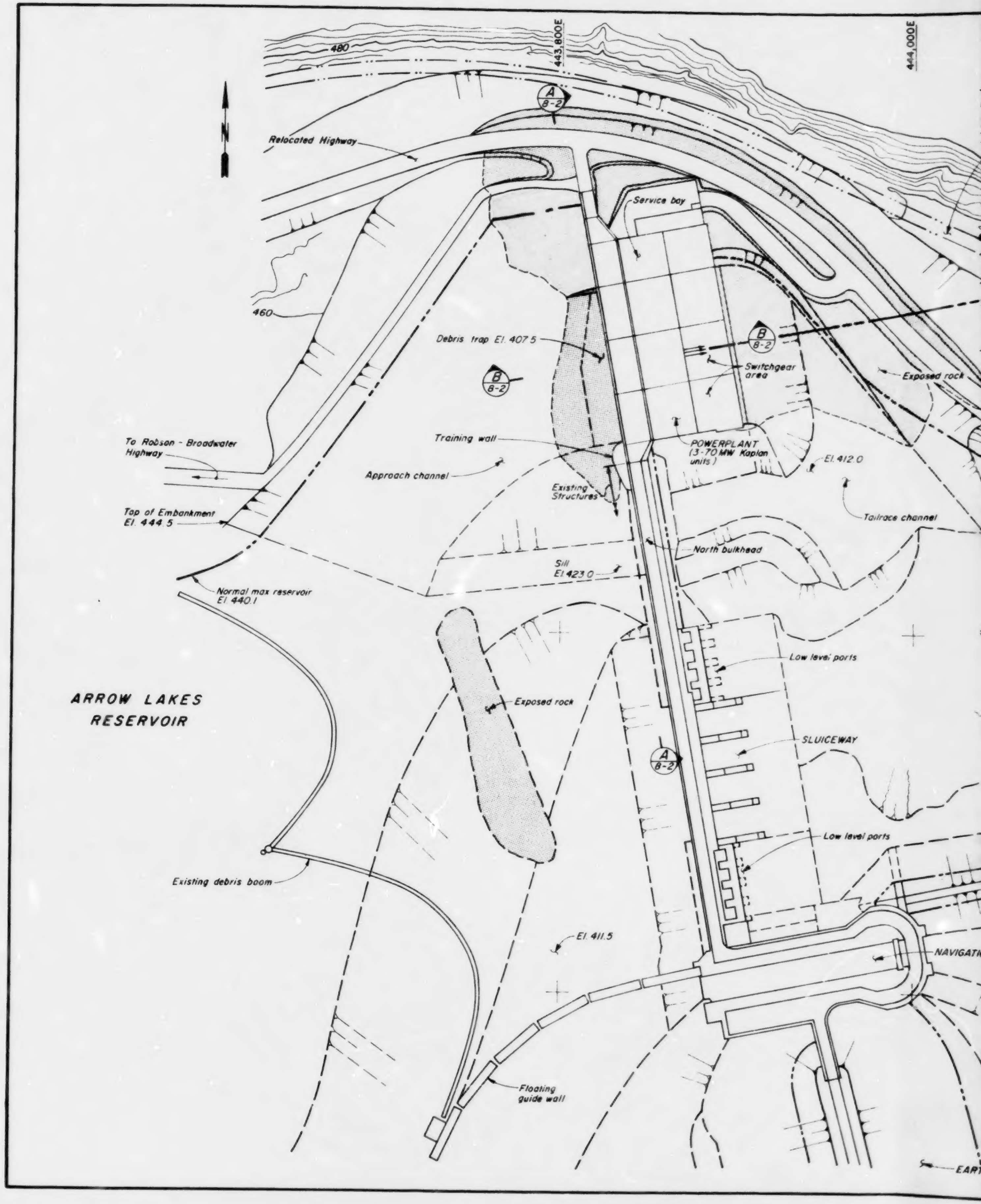
All dimensions are in metres, unless otherwise shown

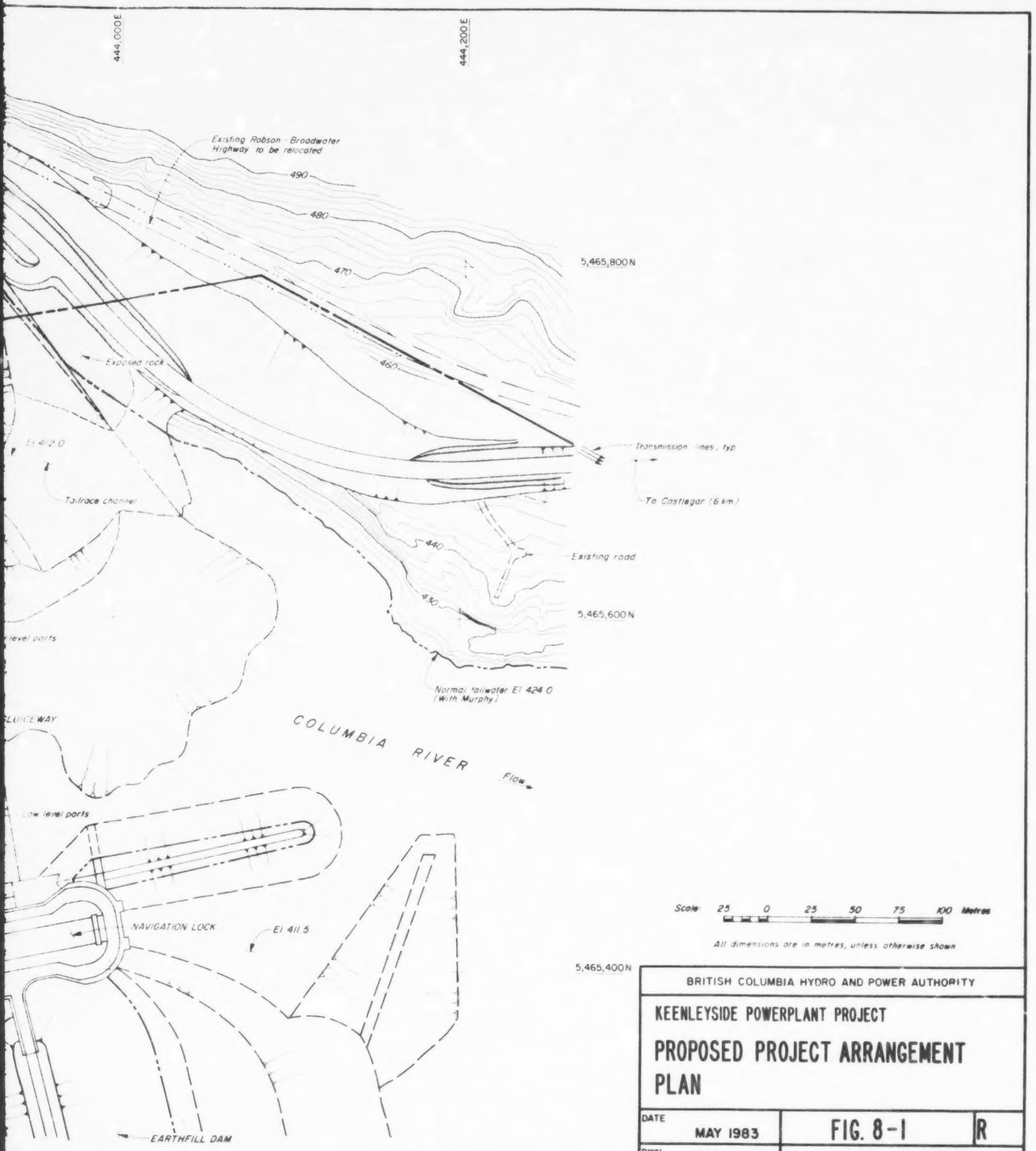
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
HYDRAULIC MODEL
INTAKE VELOCITY DISTRIBUTION
FINAL ARRANGEMENT

DATE MAY 1983	FIG. 7-4
DWN	DWG. No. 240-C14-D297

REPORT No. H1613


443,800E
444,000E
480
460
N
Relocated Highway
Service bay
Debris trap El. 407.5
Switchgear area
Exposed rock
To Robson - Broadwater Highway
Training wall
POWERPLANT (3-70 MW Kaplan units)
El. 412.0
Approach channel
Existing Structures
Tailrace channel
Top of Embankment El. 444.5
North bulkhead
Sill El. 423.0
Normal max reservoir El. 440.1
Low level ports
ARROW LAKES RESERVOIR
Exposed rock
SLUICEWAY
Low level ports
Existing debris boom
El. 411.5
NAVIGATI
Floating guide wall
EART
A 8-2
B 8-2


444,000E
444,200E
Existing Robson - Broadwater Highway to be relocated
490
480
470
460
5,465,800 N
Exposed rock
El 412.0
Tailrace channel
Transmission lines, typ
To Castlegar (6 km)
440
430
Existing road
5,465,600 N
level ports
Normal tailwater El 424.0 (With Murphy)
SLUICEWAY
COLUMBIA RIVER
Flow
Low level ports
NAVIGATION LOCK
El 411.5
EARTHFILL DAM
5,465,400 N
Scale 25 0 25 50 75 100 Metres

All dimensions are in metres, unless otherwise shown

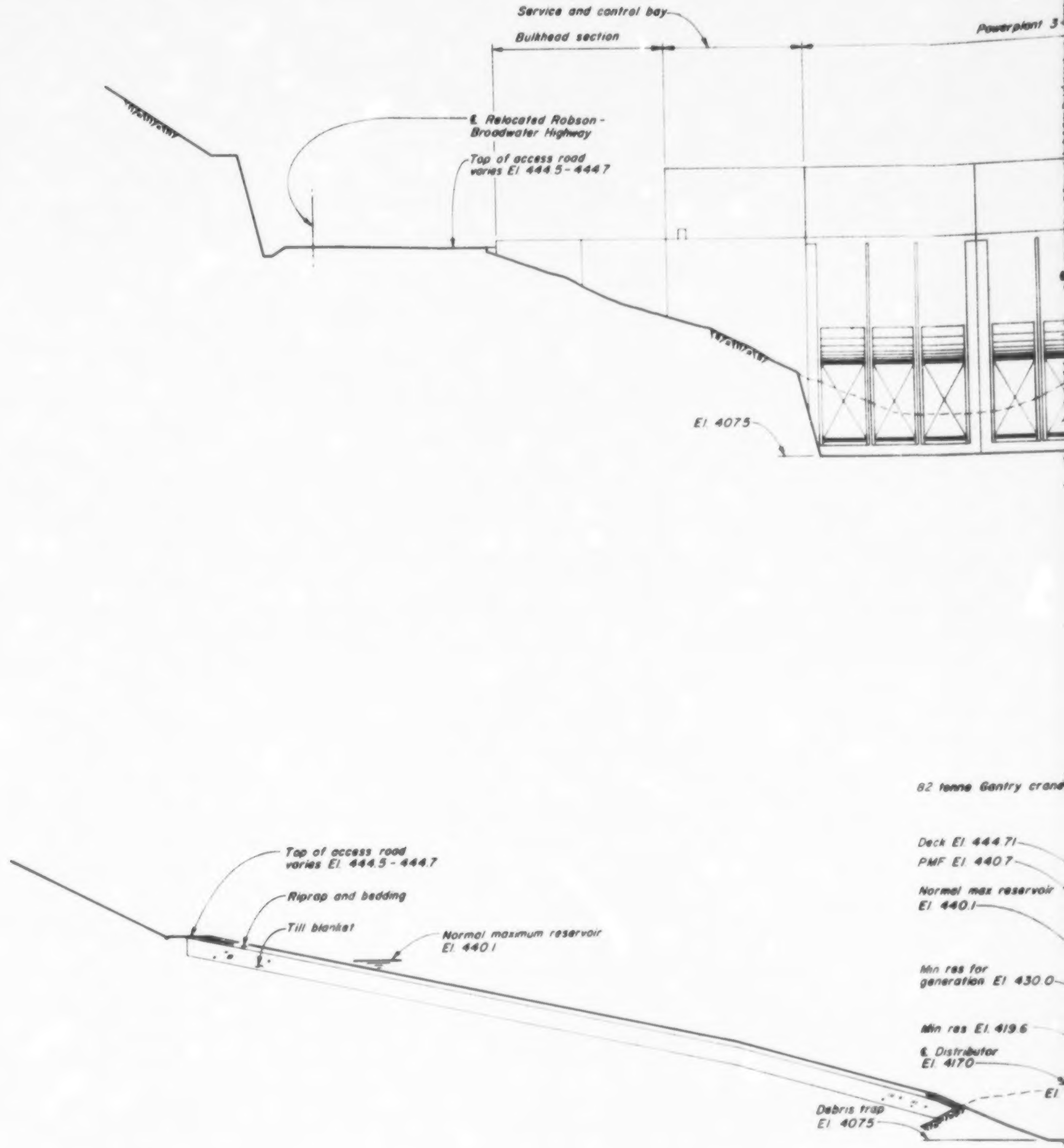
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

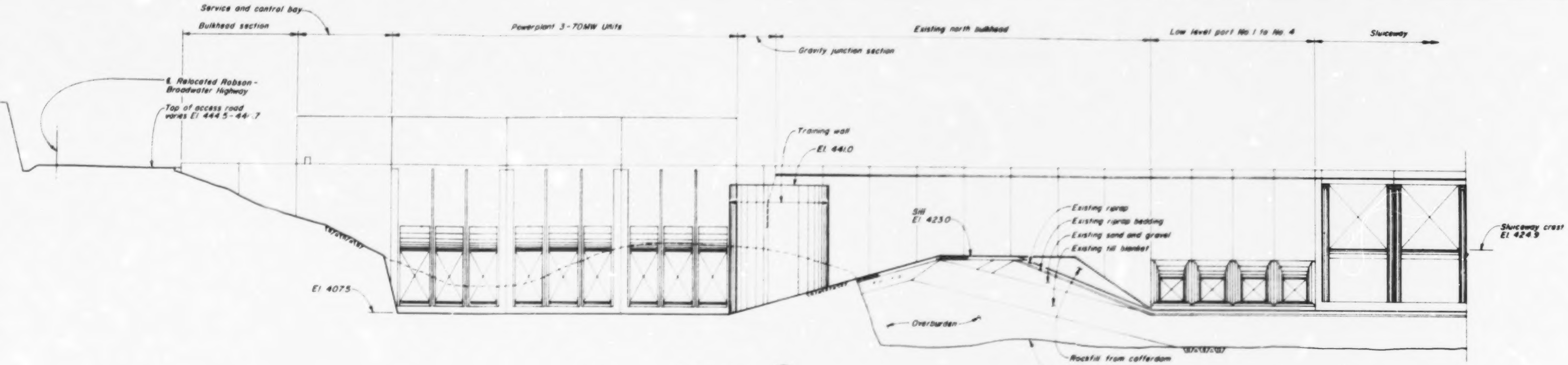
KEENLEYSIDE POWERPLANT PROJECT

PROPOSED PROJECT ARRANGEMENT PLAN

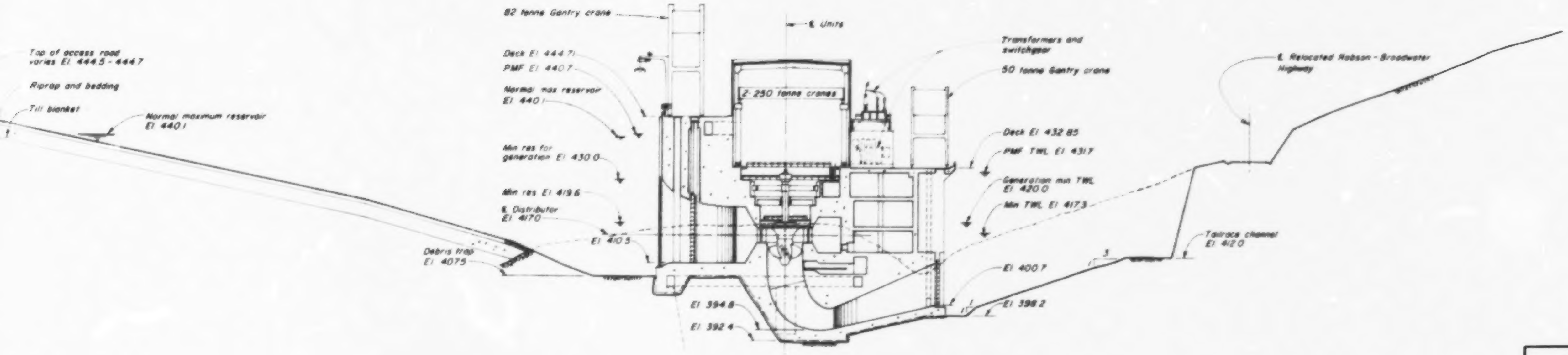
DATE MAY 1983	FIG. 8-1	R
DWN A V	DWG No. 240-C14-D298	

REPORT No. H1613


Service and control bay
Bulkhead section
Powerplant 3
℄ Relocated Robson - Broadwater Highway
Top of access road varies El 444.5 - 444.7
El 407.5
82 tonne Gantry crane
Top of access road varies El 444.5 - 444.7
Riprap and bedding
Till blanket
Normal maximum reservoir El 440.1
Deck El 444.71
PMF El 440.7
Normal max reservoir El 440.1
Min res for generation El 430.0
Min res El 419.6
℄ Distributor El 417.0
El
Debris trap El 407.5


Service and control bay
Bulkhead section
Powerplant 3-70MW Units
Existing north bulkhead
Low level port No 1 to No 4
Sluiceway
Gravity junction section
℄ Relocated Robson-Broadwater Highway
Top of access road varies El 444.5-444.7
Training wall
El 441.0
SHI El 423.0
Existing riprap
Existing riprap bedding
Existing sand and gravel
Existing till blanket
Sluiceway crest El 424.9
El 407.5
Overburden
Rockfill from cofferdam
Assumed rock profile

ELEVATION (A/8-1)


Top of access road varies El 444.5-444.7
Riprap and bedding
Till blanket
Normal maximum reservoir El 440.1
82 tonne Gantry crane
Deck El 444.71
PMF El 440.7
Normal max reservoir El 440.1
Min res for generation El 430.0
Min res El 419.6
℄ Distributor El 417.0
El 410.5
Debris trap El 407.5
El 394.8
El 392.4
℄ Units
2-250 tonne cranes
Transformers and switchgear
50 tonne Gantry crane
Deck El 432.85
PMF TWL El 431.7
Generation min TWL El 420.0
Min TWL El 417.3
El 400.7
El 398.2
Tailrace channel El 412.0
℄ Relocated Robson-Broadwater Highway
3
1

SECTION (B/8-1)

Scale: 10 0 10 20 30 40 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

PROPOSED PROJECT ARRANGEMENT ELEVATION AND SECTION

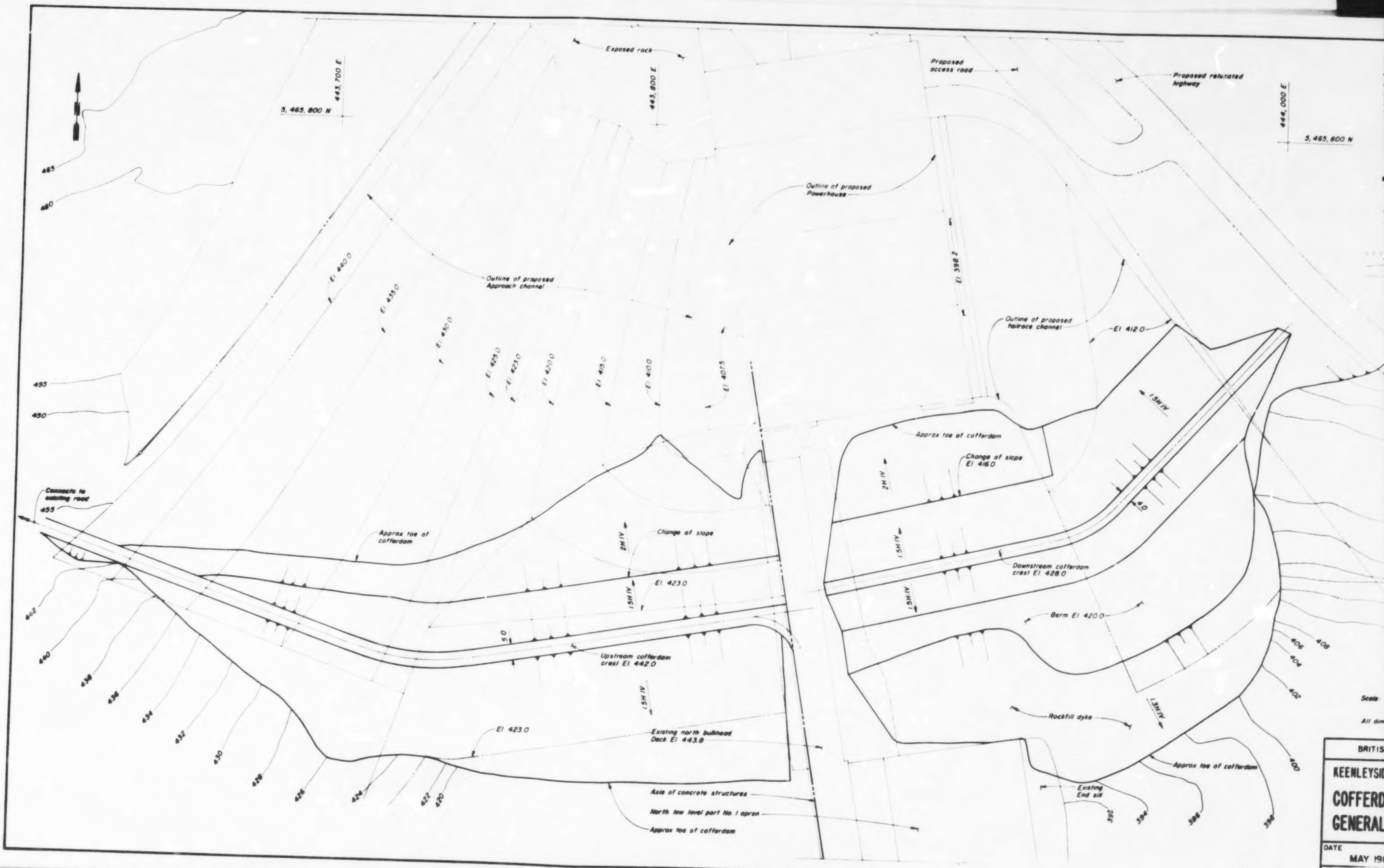
DATE MAY 1983

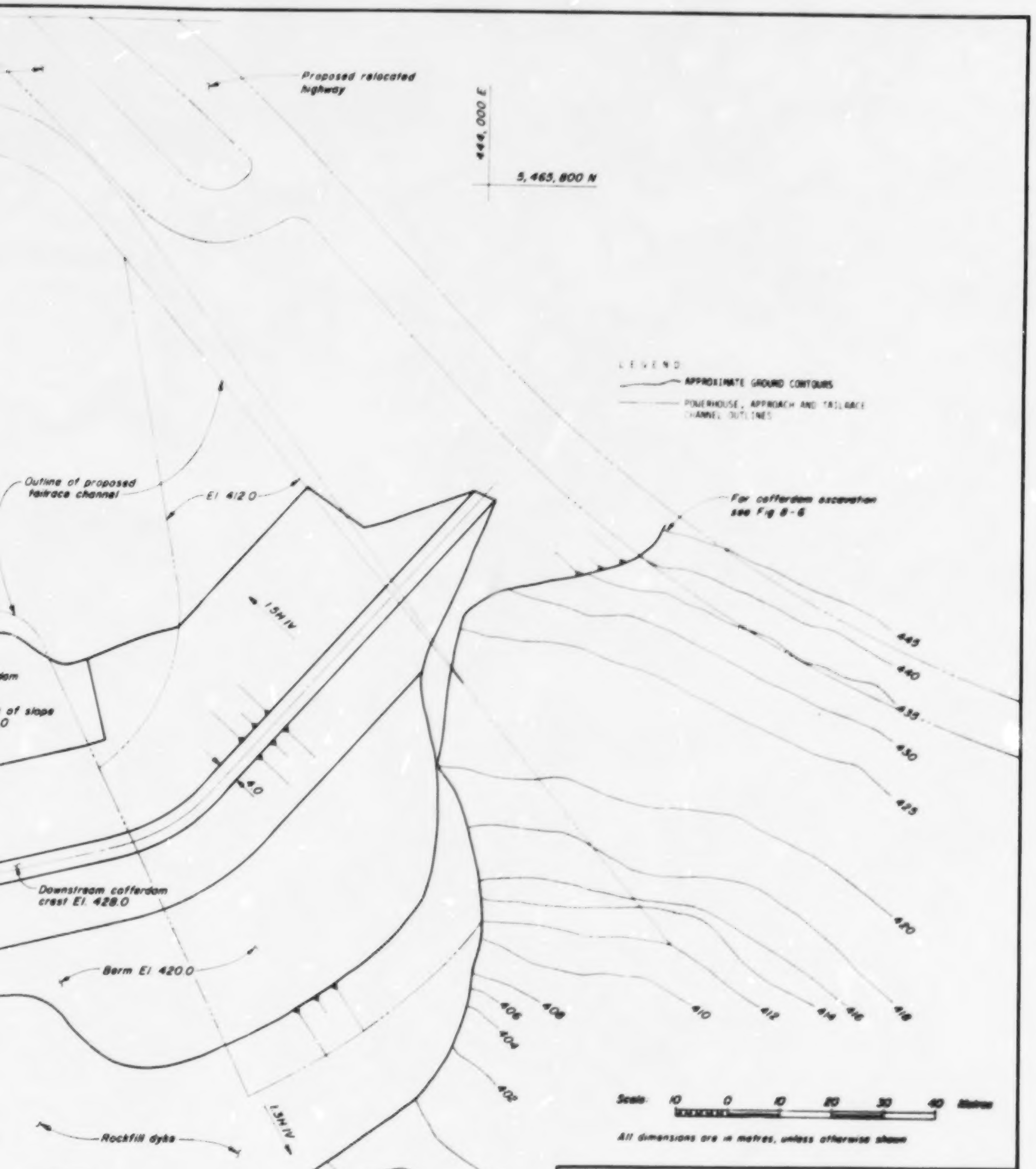
FIG. 8-2

DWN SM

DWG No 240-C14-U299

REPORT No. H1613


Exposed rock
Proposed access road
Proposed relocated highway
5, 465, 800 N
443, 700 E
443, 800 E
444, 000 E
5, 465, 800 N
465
460
455
450
455
Outline of proposed Powerhouse
Outline of proposed Approach channel
El 440.0
El 435.0
El 430.0
El 425.0
El 423.0
El 420.0
El 415.0
El 410.0
El 407.5
El 398.2
Outline of proposed tailrace channel
El 412.0
1.5H:1V
Approx toe of cofferdam
Change of slope El. 416.0
2H:1V
Connects to existing road
Approx toe of cofferdam
2H:1V
Change of slope
El 423.0
1.5H:1V
1.5H:1V
Downstream cofferdam crest El. 428.0
1.5H:1V
4.0
Berm El. 420.0
5.0
Upstream cofferdam crest El. 442.0
1.5H:1V
El 423.0
Existing north bulkhead Deck El. 443.8
Rockfill dyke
1.3H:1V
Approx toe of cofferdam
Existing End sill
Axis of concrete structures
North low level port No. 1 apron
Approx toe of cofferdam
442
440
438
436
434
432
430
428
426
424
422
420
392
394
396
398
400
402
404
406
408
Scale
All dim
BRITIS
KEENLEYSID
COFFERD
GENERAL
DATE
MAY 19


Proposed relocated highway
444,000 E
5,465,800 N
LEGEND
APPROXIMATE GROUND CONTOURS
POWERHOUSE, APPROACH AND TAILRACE CHANNEL OUTLINES
Outline of proposed tailrace channel
El 412.0
For cofferdam excavation see Fig 8-6
1.5H:1V
of slope
Downstream cofferdam crest El 428.0
Berm El 420.0
Rockfill dyke
Approx toe of cofferdam
Existing End sill
445
440
435
430
425
420
418
416
414
412
410
408
406
404
402
400
398
396
394
392
Scale 10 0 10 20 30 40 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

COFFERDAMS
GENERAL ARRANGEMENT

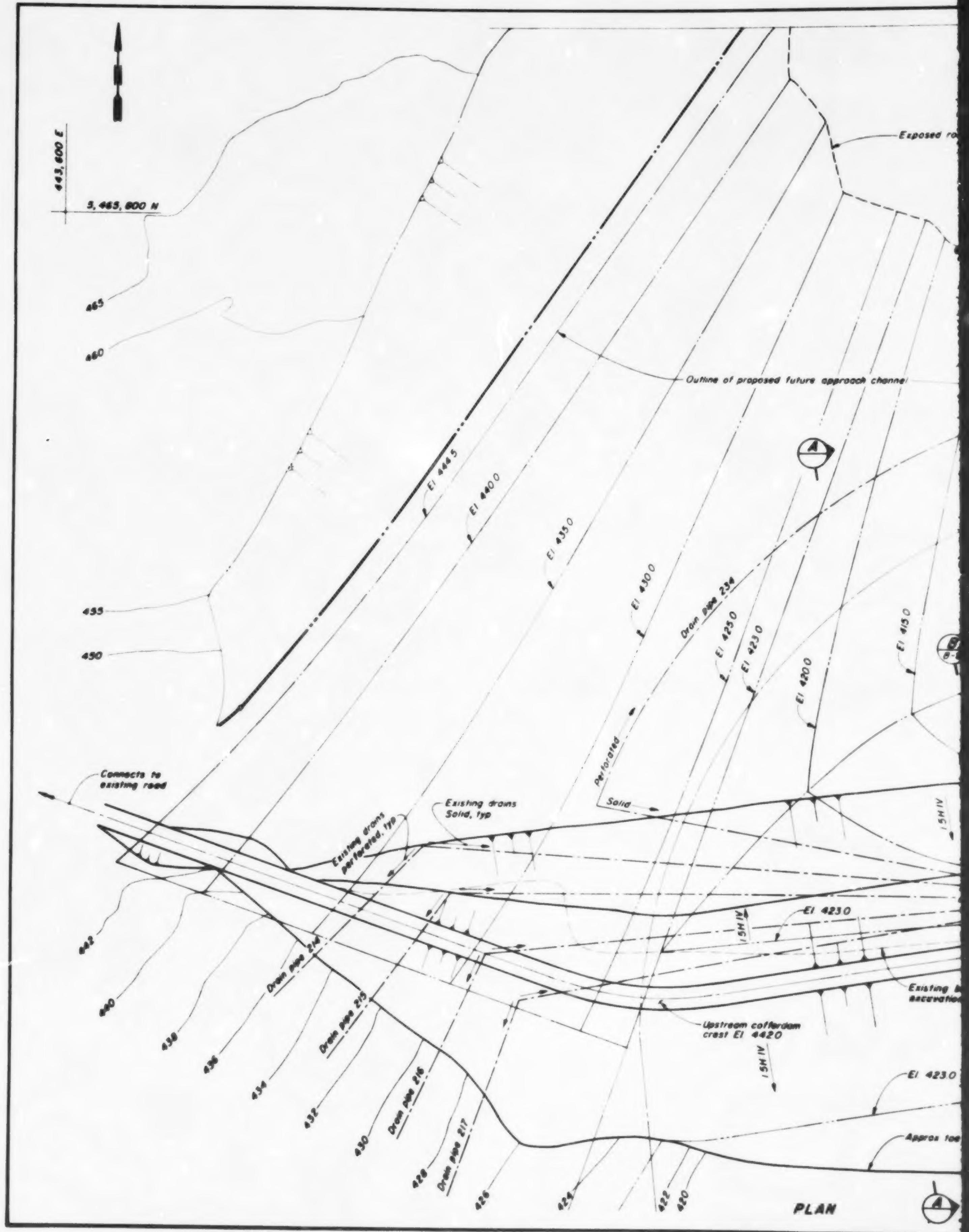
DATE MAY 1983

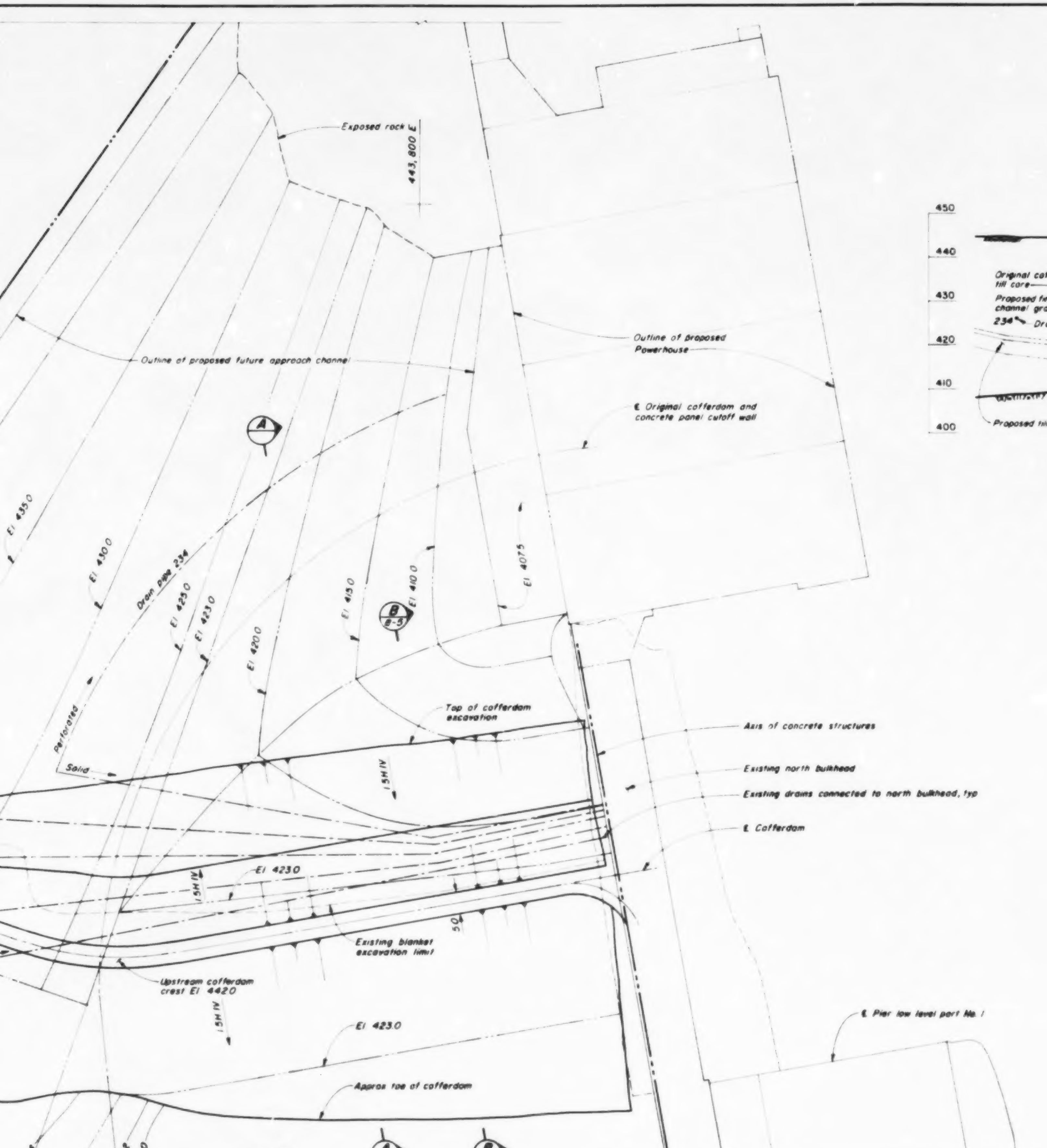
FIG. 8-3

DWN SM

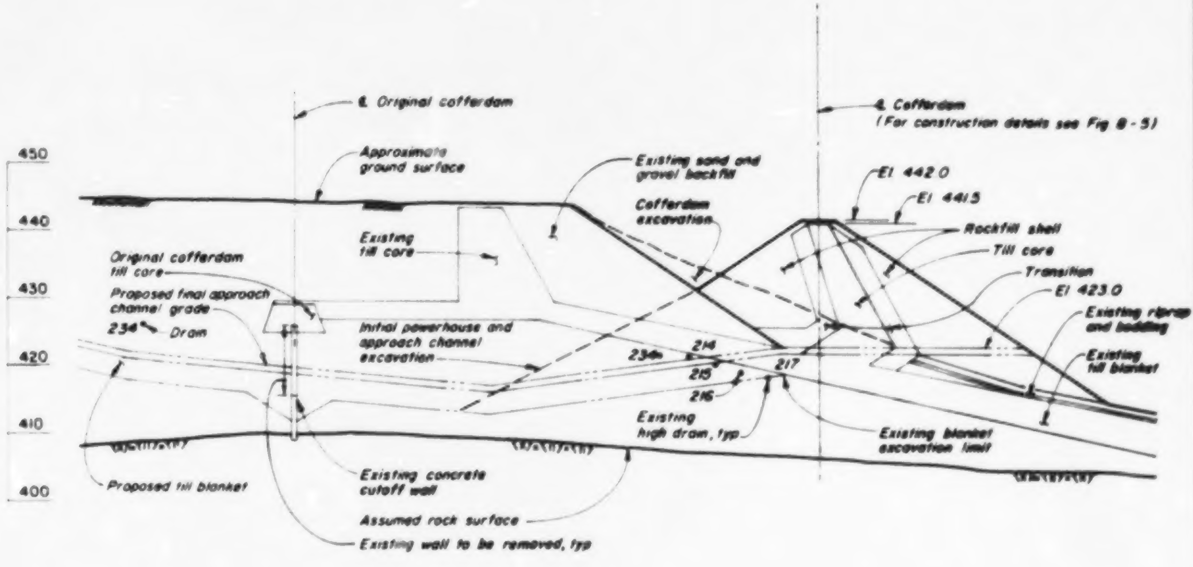
DWG No 240-C14-U300

REPORT No [illegible]


443,600 E
5,465,800 N
Exposed ro
Outline of proposed future approach channel
465
460
455
450
El 444.5
El 440.0
El 435.0
El 430.0
Drain pipe 234
El 425.0
El 423.0
El 420.0
El 415.0
Perforated
Solid
Connects to existing road
Existing drains perforated, typ
Existing drains Solid, typ
1.5H:1V
El 423.0
Existing
Upstream cofferdam crest El 442.0
El 423.0
Approx toe
Drain pipe 214
Drain pipe 215
Drain pipe 216
Drain pipe 217
442
440
438
436
434
432
430
428
426
424
422
420
PLAN
A


Exposed rock
443,800 E
Outline of proposed future approach channel
Outline of proposed Powerhouse
℄ Original cofferdam and concrete panel cutoff wall
A
El 435.0
El 430.0
Drain pipe 234
El 425.0
El 423.0
El 420.0
El 415.0
B
8-5
El 410.0
El 407.5
Perforated
Solid
Top of cofferdam excavation
Axis of concrete structures
Existing north bulkhead
Existing drains connected to north bulkhead, typ
1.5H:1V
℄ Cofferdam
El 423.0
1.5H:1V
50
Existing blanket excavation limit
Upstream cofferdam crest El 442.0
1.5H:1V
El 423.0
℄ Pier low level port No. 1
Approx toe of cofferdam
424
422
420

PLAN A B 8-5


℄ Original cofferdam
℄ Cofferdam
(For construction details see Fig 8 - 5)
450
440
430
420
410
400
Approximate ground surface
Existing sand and gravel backfill
El 442.0
El 441.5
Cofferdam excavation
Rockfill shell
Existing till core
Till core
Original cofferdam till core
Transition
Proposed final approach channel grade
El 423.0
234 Drain
Initial powerhouse and approach channel excavation
Existing riprap and bedding
234
214
215
216
217
Existing till blanket
Existing high drain, typ
Existing blanket excavation limit
Proposed till blanket
Existing concrete cutoff wall
Assumed rock surface
Existing wall to be removed, typ

SECTION A

NOTE

FOR CONSTRUCTION SEQUENCE OF UPSTREAM COFFERDAM SEE FIG. 8-5.

LEGEND

〰 APPROXIMATE GROUND CONTOURS

—··— PROPOSED POWERHOUSE AND APPROACH CHANNEL OUTLINES

—·— EXISTING DRAIN PIPES

Scale: 10 0 10 20 30 40 Metres

All dimensions are in metres, unless otherwise shown

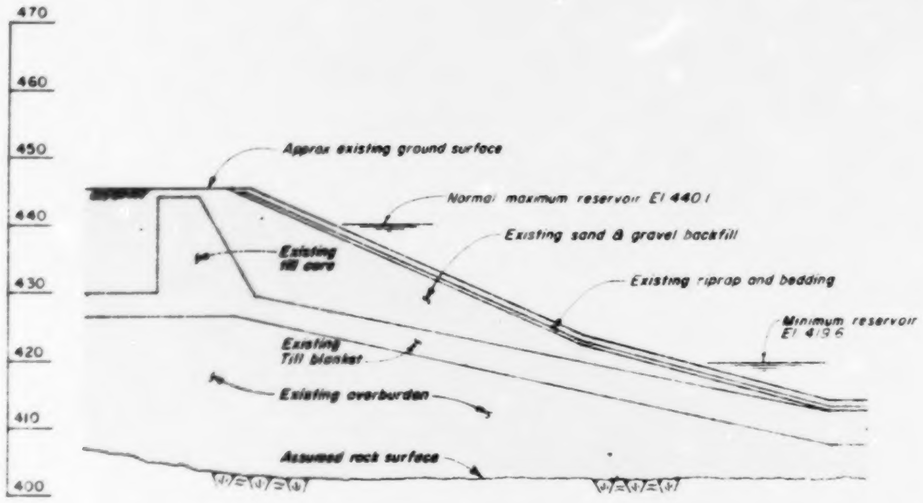
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

UPSTREAM COFFERDAM
PLAN AND SECTION

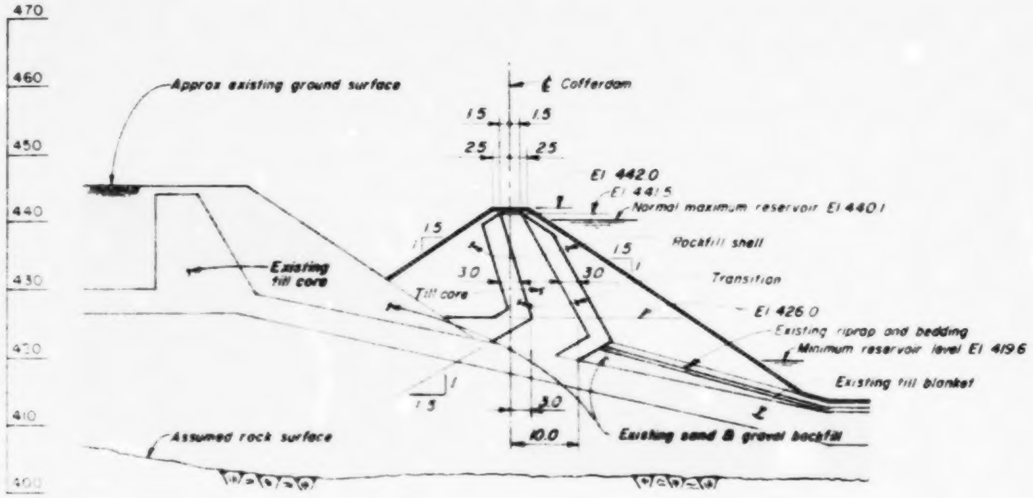
DATE MAY 1983	FIG. 8-4
DWN SM	DWG No 240-C14-U301

REPORT No [illegible]


470
460
450
440
430
420
410
400
Approx existing ground surface
Normal maximum reservoir El 440.1
Existing sand & gravel backfill
Existing till core
Existing riprap and bedding
Minimum reservoir El 419.6
Existing Till blanket
Existing overburden
Assumed rock surface

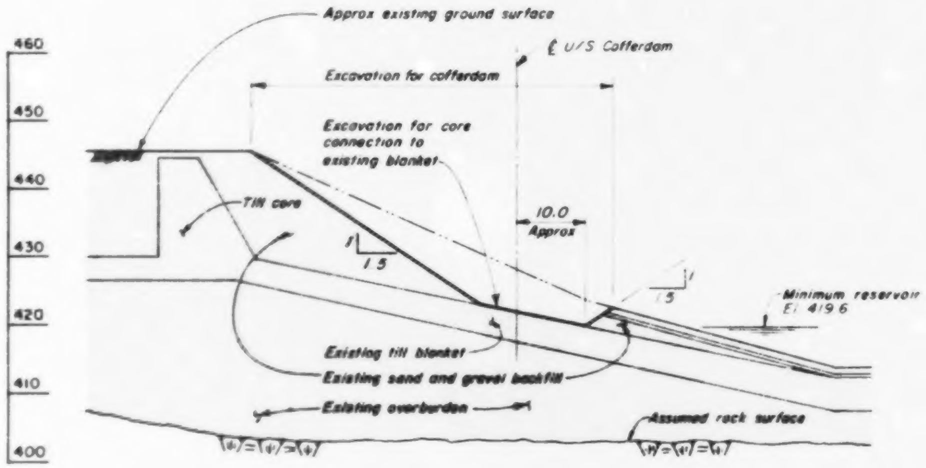
SECTION $\frac{B}{8\text{-}4}$

EXISTING NORTH BANK


470
460
450
440
430
420
410
400
Approx existing ground surface
℄ Cofferdam
1.5
1.5
2.5
2.5
El 442.0
El 441.5
Normal maximum reservoir El 440.1
Rockfill shell
1.5
1
Existing till core
3.0
3.0
Transition
Till core
El 426.0
Existing riprap and bedding
Minimum reservoir level El 419.6
Existing till blanket
1
1.5
3.0
10.0
Assumed rock surface
Existing sand & gravel backfill

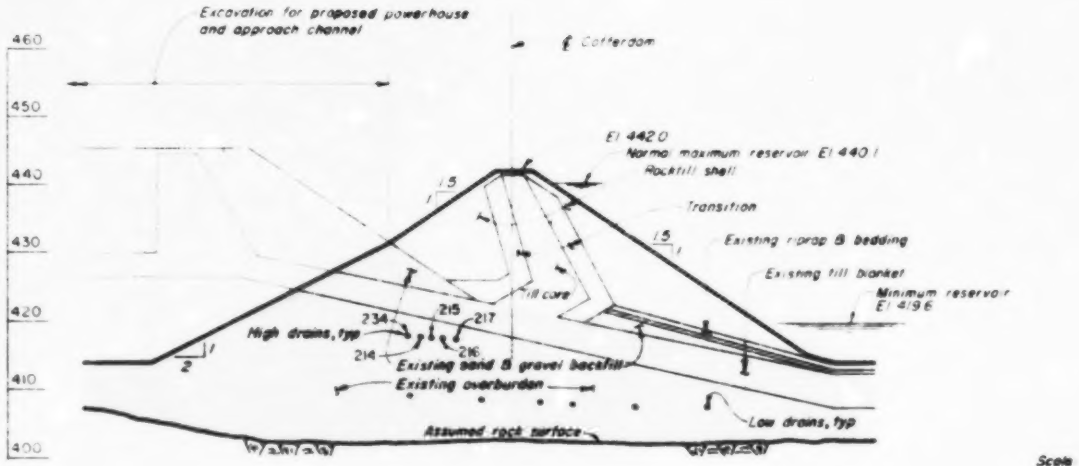
SECTION $\frac{B}{8\text{-}4}$

STAGE 2 COFFERDAM CONSTRUCTION


460
450
440
430
420
410
400
Approx existing ground surface
℄ U/S Cofferdam
Excavation for cofferdam
Excavation for core connection to existing blanket
Till core
10.0 Approx
1
1.5
1
1.5
Minimum reservoir El 419.6
Existing till blanket
Existing sand and gravel backfill
Existing overburden
Assumed rock surface

SECTION $\frac{B}{8\text{-}4}$

STAGE I COFFERDAM EXCAVATION


460
450
440
430
420
410
400
Excavation for proposed powerhouse and approach channel
℄ Cofferdam
El 442.0
Normal maximum reservoir El 440.1
Rockfill shell
1.5
1
Transition
1.5
1
Existing riprap & bedding
Existing till blanket
Minimum reservoir El 419.6
Till core
234
215
217
High drains, typ
214
216
Existing sand & gravel backfill
2
1
Existing overburden
Low drains, typ
Assumed rock surface

SECTION $\frac{B}{8\text{-}4}$

STAGE 3 POWERHOUSE & APPROACH CHANNEL EXCAVATION

Scale 10 0 10 20 30 40 Metres

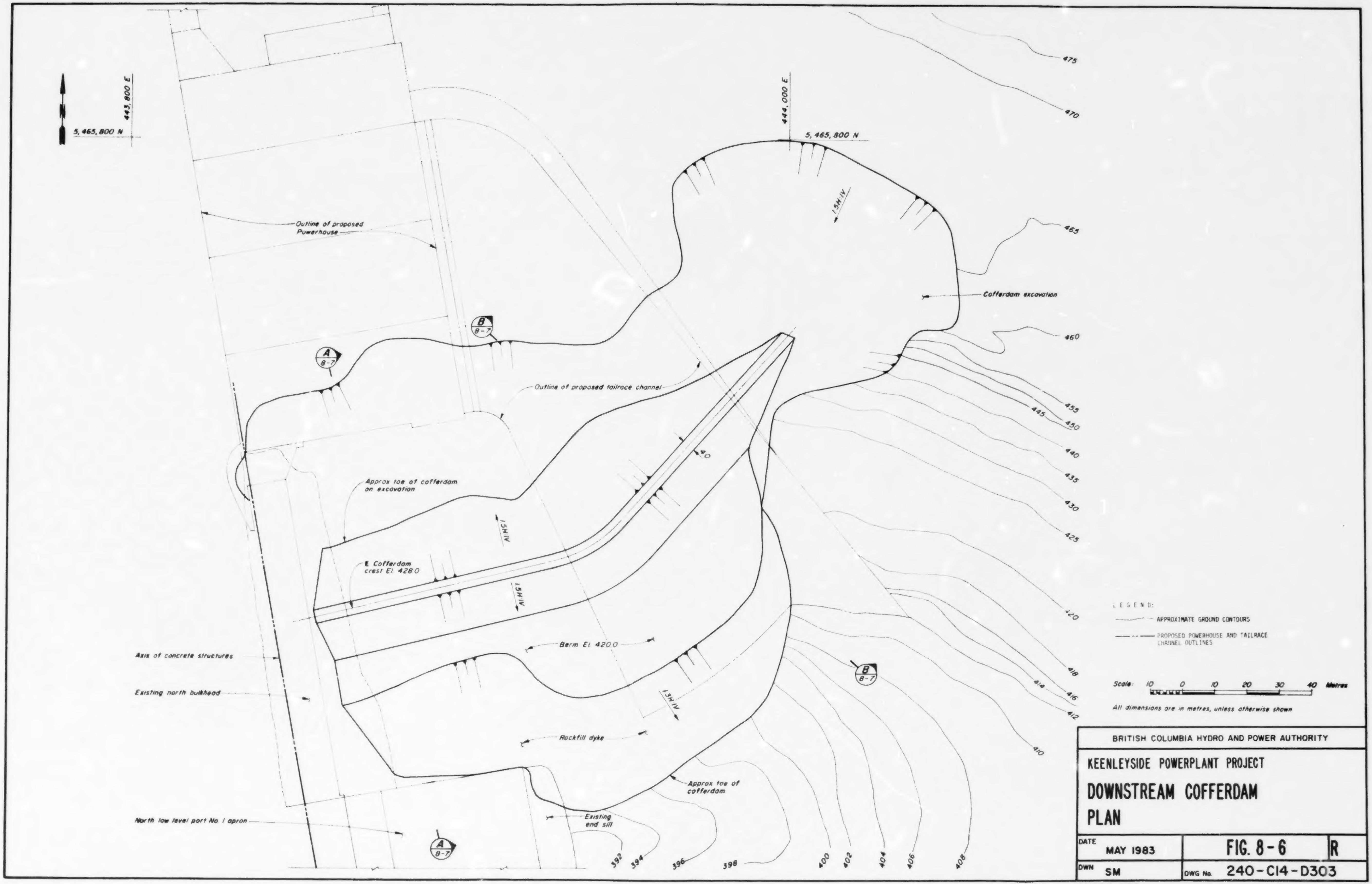
All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
UPSTREAM COFFERDAM
CONSTRUCTION SEQUENCE
SECTIONS

DATE MAY 1983	FIG. 8-5	R
DWN A Sz	DWG No. 240-C14-D302	

REPORT No. H1613


443,800 E
5,465,800 N
444,000 E
5,465,800 N
N
Outline of proposed Powerhouse
Cofferdam excavation
1.5H:1V
Outline of proposed tailrace channel
B
8-7
A
8-7
4.0
Approx toe of cofferdam on excavation
℄ Cofferdam crest El. 428.0
1.5H:1V
1.5H:1V
Berm El. 420.0
1.3H:1V
Axis of concrete structures
Existing north bulkhead
Rockfill dyke
Approx toe of cofferdam
Existing end sill
North low level port No. 1 apron
A
8-7
B
8-7
475
470
465
460
455
445
450
440
435
430
425
420
418
414
416
412
410
392
394
396
398
400
402
404
406
408
LEGEND:
APPROXIMATE GROUND CONTOURS
PROPOSED POWERHOUSE AND TAILRACE CHANNEL OUTLINES
Scale: 10 0 10 20 30 40 Metres
All dimensions are in metres, unless otherwise shown

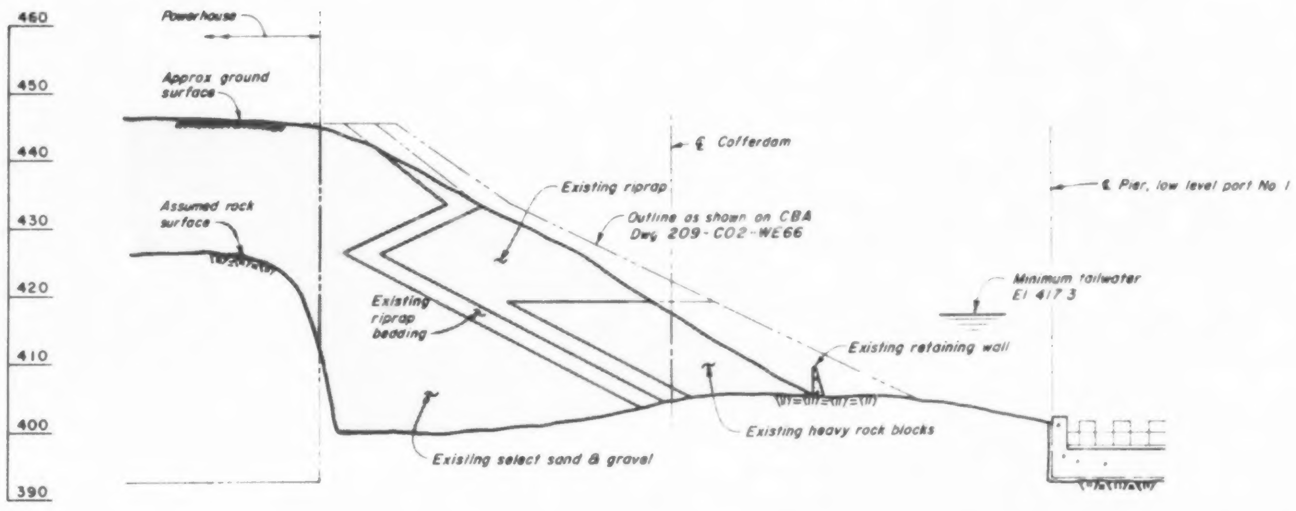
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

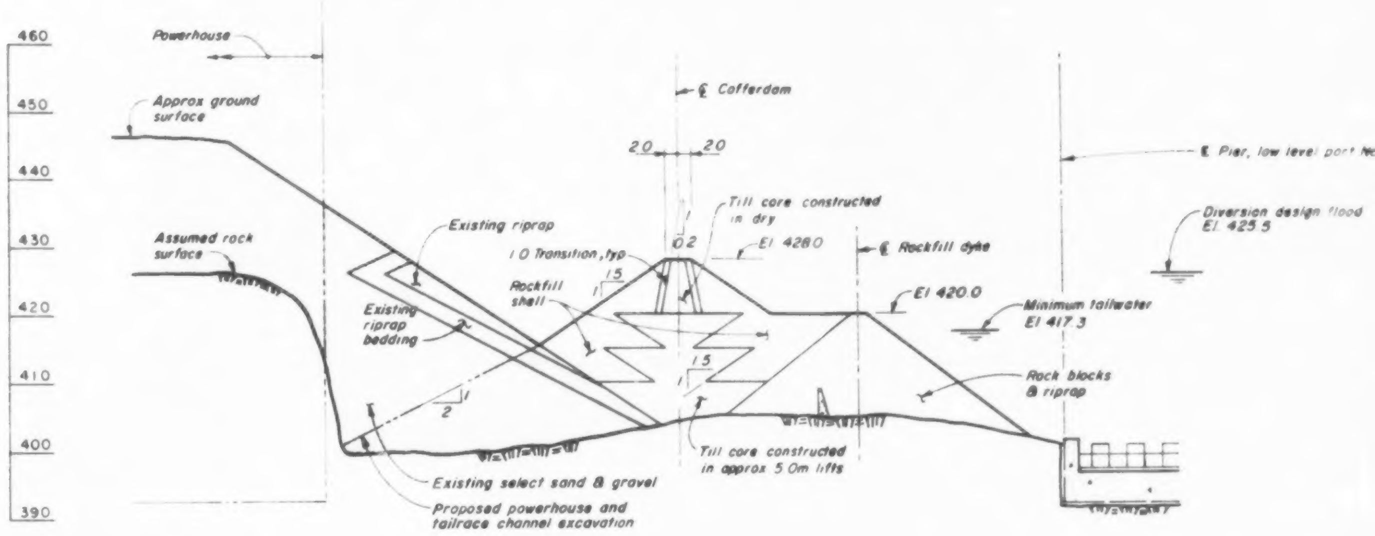
DOWNSTREAM COFFERDAM
PLAN

DATE MAY 1983
DWN SM
FIG. 8-6
R
DWG No. 240-C14-D303

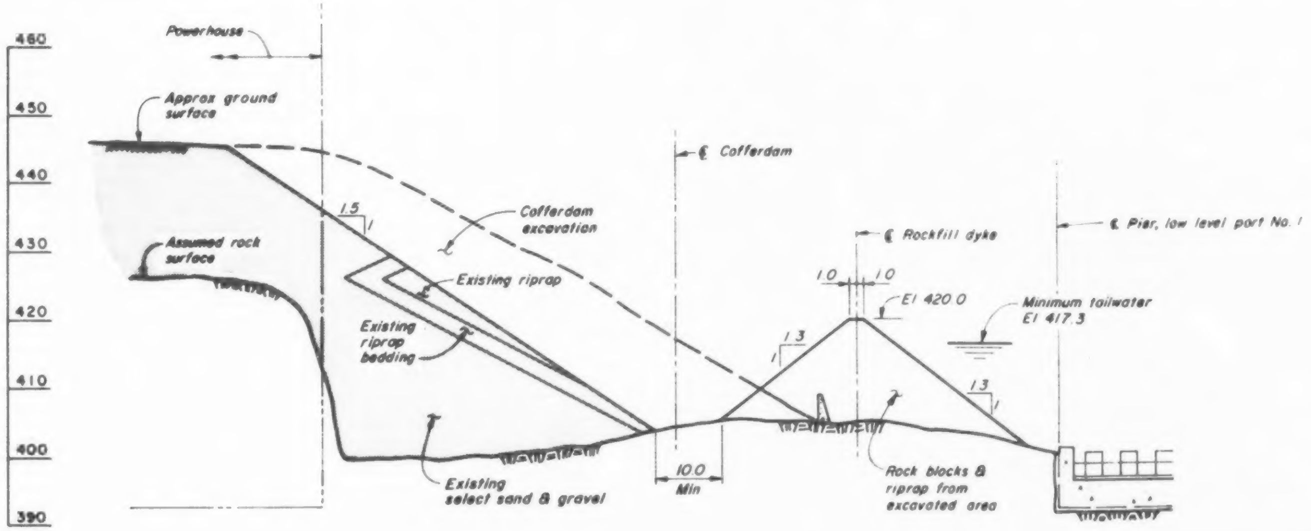
REPORT No. H1613


460
450
440
430
420
410
400
390
Powerhouse
Approx ground surface
Assumed rock surface
Existing riprap
Outline as shown on CBA Dwg 209-C02-WE66
℄ Cofferdam
℄ Pier, low level port No 1
Minimum tailwater El 417.3
Existing riprap bedding
Existing retaining wall
Existing heavy rock blocks
Existing select sand & gravel

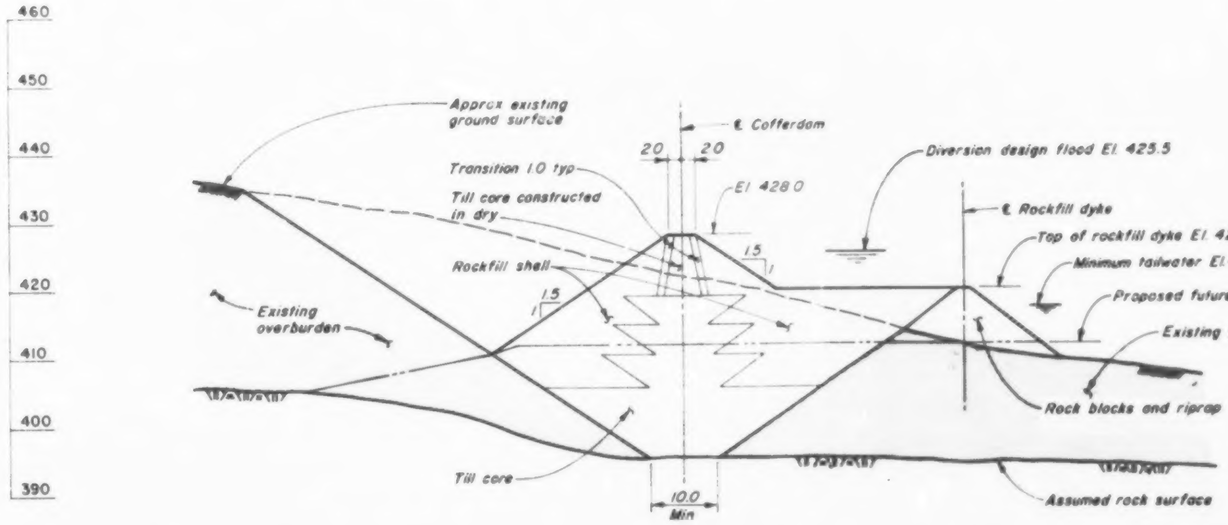
SECTION A/8-6
(Existing)


460
450
440
430
420
410
400
390
Powerhouse
Approx ground surface
Assumed rock surface
℄ Cofferdam
2.0
2.0
℄ Pier, low level port No
Diversion design flood El 425.5
Existing riprap
Till core constructed in dry
0.2
1
1.0 Transition, typ
El 428.0
℄ Rockfill dyke
Rockfill shell
1.5
1
El 420.0
Minimum tailwater El 417.3
Existing riprap bedding
1.5
1
2
1
Rock blocks & riprap
Till core constructed in approx 5.0m lifts
Existing select sand & gravel
Proposed powerhouse and tailrace channel excavation

SECTION A/8-6
(Stage 2)


460
450
440
430
420
410
400
390
Powerhouse
Approx ground surface
Assumed rock surface
℄ Cofferdam
1.5
1
Cofferdam excavation
Existing riprap
Existing riprap bedding
℄ Rockfill dyke
℄ Pier, low level port No. 1
1.0
1.0
El 420.0
Minimum tailwater El 417.3
1.3
1
1.3
1
10.0 Min
Existing select sand & gravel
Rock blocks & riprap from excavated area

SECTION A/8-6
(Stage 1)


460
450
440
430
420
410
400
390
Approx existing ground surface
℄ Cofferdam
2.0
2.0
Transition 1.0 typ
Till core constructed in dry
El 428.0
Diversion design flood El 425.5
℄ Rockfill dyke
Top of rockfill dyke El 420.0
Minimum tailwater El 417.3
Rockfill shell
1.5
1
1.5
1
Proposed future tailrace channel
Existing overburden
Existing overburden
Rock blocks and riprap
Till core
10.0 Min
Assumed rock surface

SECTION B/8-6
(Stage 2)

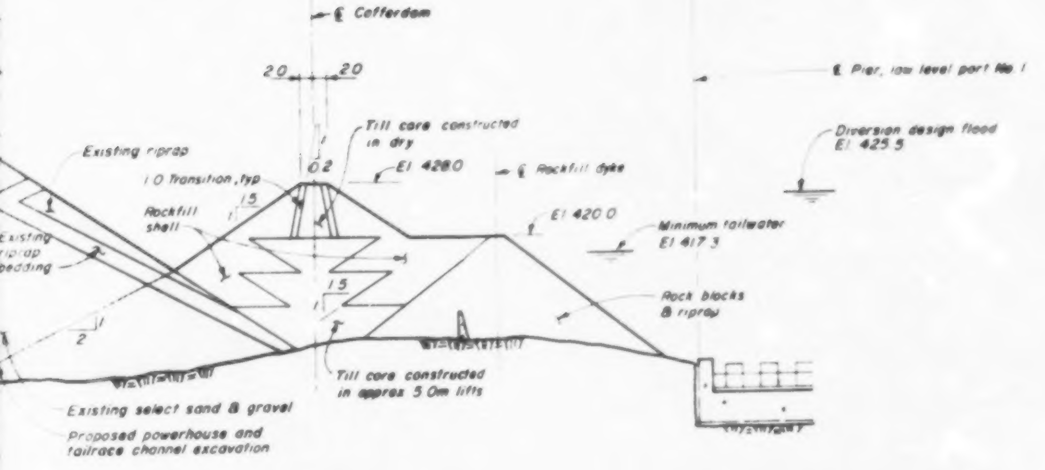
KEE
DO
CON
SE

DATE

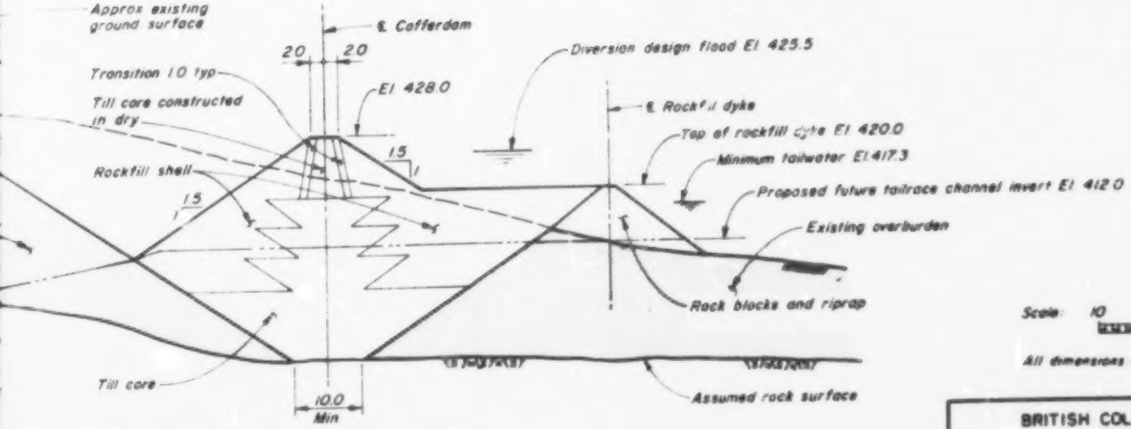
DWN

REPORT

REPORT No. H1613


℄ Cofferdam
2.0
2.0
℄ Pier, low level port No. 1
Till core constructed in dry
Diversion design flood El 425.5
Existing riprap
0.2
El 428.0
℄ Rockfill dyke
1.0 Transition, typ
1.5
1
Rockfill shell
El 420.0
Minimum tailwater El 417.3
Existing riprap bedding
1.5
1
Rock blocks & riprap
2
1
Till core constructed in approx 5.0m lifts
Existing select sand & gravel
Proposed powerhouse and tailrace channel excavation

SECTION $\frac{A}{8\text{-}6}$
(Stage 2)


Approx existing ground surface
℄ Cofferdam
2.0
2.0
Diversion design flood El 425.5
Transition 1.0 typ
El 428.0
Till core constructed in dry
℄ Rockfill dyke
Top of rockfill dyke El 420.0
1.5
1
Minimum tailwater El 417.3
Rockfill shell
Proposed future tailrace channel invert El 412.0
1.5
1
Existing overburden
Rock blocks and riprap
Till core
10.0
Min
Assumed rock surface

SECTION $\frac{B}{8\text{-}6}$
(Stage 2)

Scale: 10 0 10 20 30 40 Metres

All dimensions are in metres, unless otherwise shown

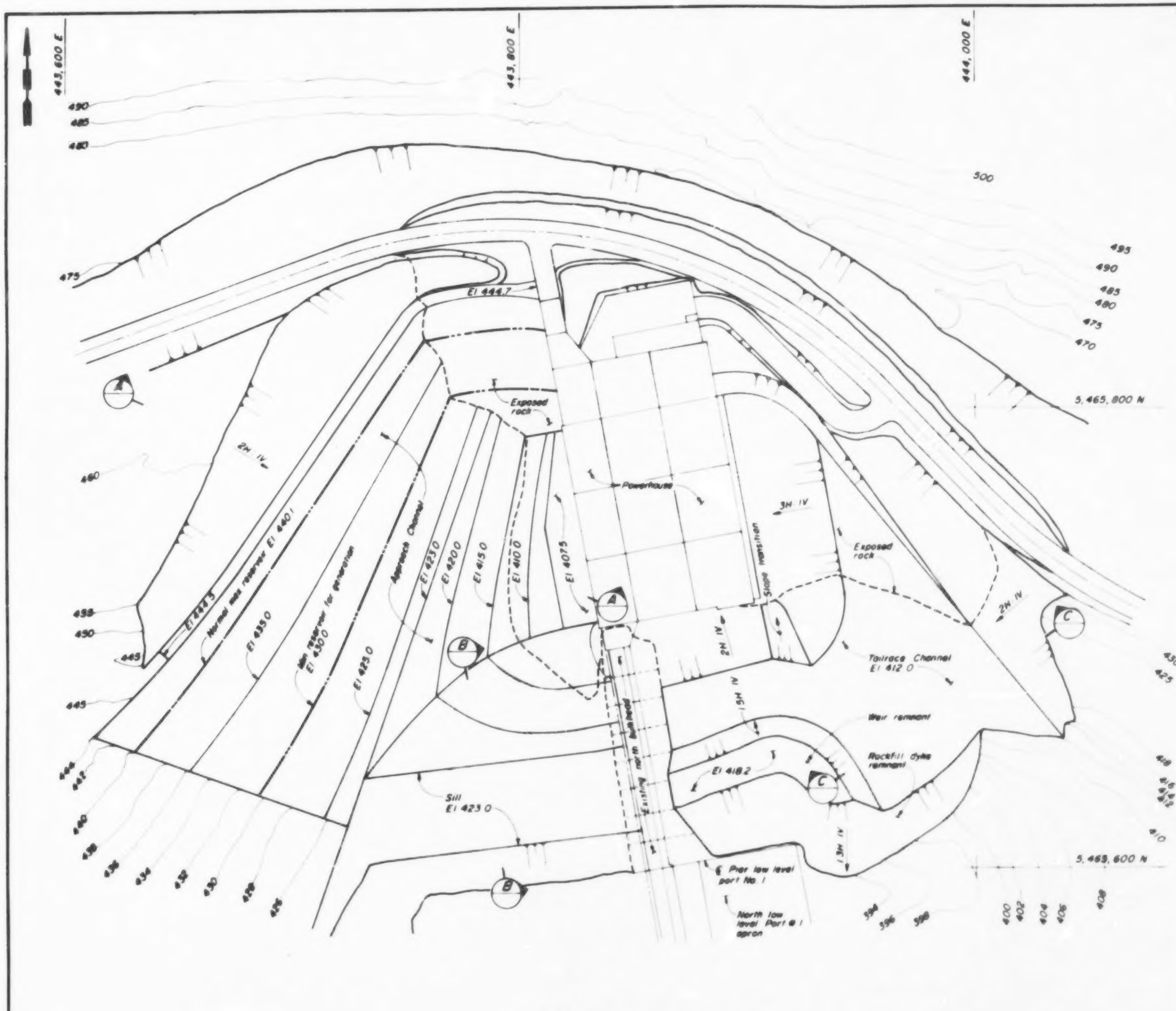
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
DOWNSTREAM COFFERDAM
CONSTRUCTION SEQUENCE
SECTIONS

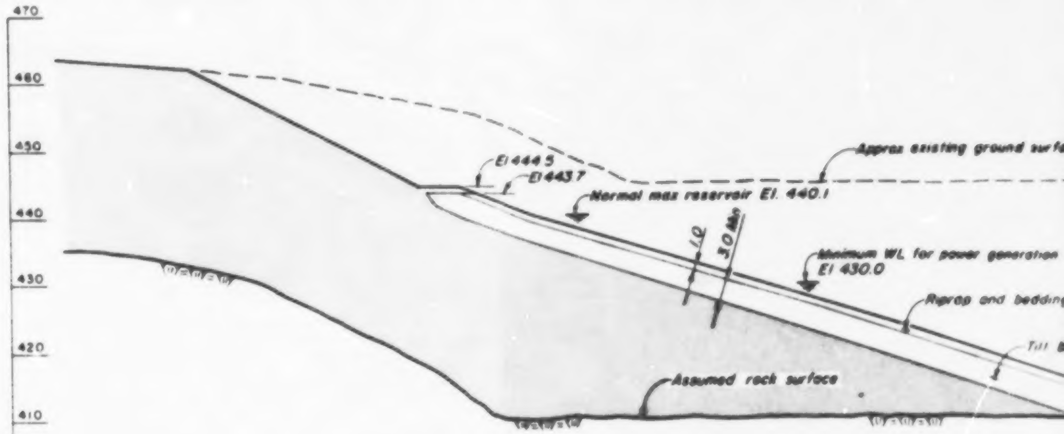
DATE MAY 1983	FIG. 8-7
DWN DS/SM	DWG No. 240-C14-U304

REPORT No. H1613

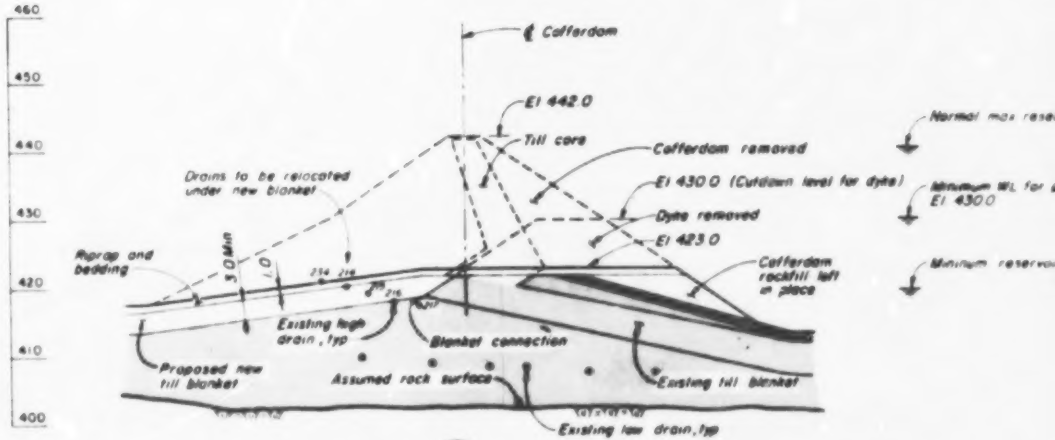
DATE
MAY 1


443,600 E
443,800 E
444,000 E
490
485
480
500
495
490
485
480
475
470
475
5,465,800 N
5,465,600 N
El 444.7
Exposed rock
Powerhouse
2H 1V
3H 1V
Slope transition
Exposed rock
Approach Channel
Normal max reservoir El 440.1
El 444.5
El 435.0
Min reservoir for generation El 430.0
El 425.0
El 423.0
El 420.0
El 415.0
El 410.0
El 407.5
2H 1V
2H 1V
1.5H 1V
1.3H 1V
Tailrace Channel El 412.0
Weir remnant
Rockfill dyke remnant
El 418.2
Sill El 423.0
℄ Prior low level port No. 1
North low level Port # 1 apron
Existing north bulkhead
A
B
C
460
438
440
445
445
444
442
440
438
436
434
432
430
428
426
430
425
418
416
414
412
410
394
396
398
400
402
404
406
408

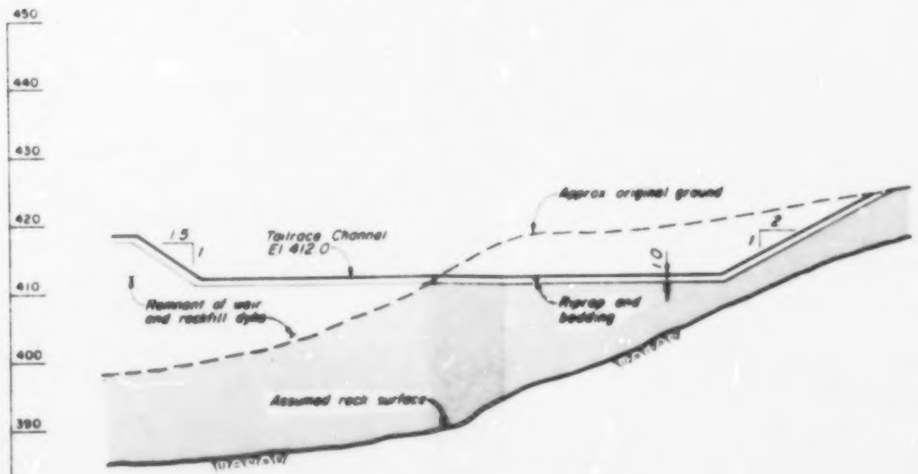
PLAN
Scale A


470
460
450
440
430
420
410
400
El 444.5
El 443.7
Normal max reservoir El. 440.1
Approx existing ground surface
Minimum WL for power generation
El 430.0
1.0
3.0 Min
Riprap and bedding
Till
Assumed rock surface

SECTION A
Scale B


460
450
440
430
420
410
400
℄ Cofferdam
El 442.0
Till core
Cofferdam removed
El 430.0 (Cutdown level for dyke)
Dyke removed
El 423.0
Drains to be relocated under new blanket
Riprap and bedding
3.0 Min
1.0
Existing high drain, typ
Blanket connection
Cofferdam rockfill left in place
Proposed new till blanket
Assumed rock surface
Existing till blanket
Existing low drain, typ
Normal max rese
Minimum WL for
El 430.0
Minimum reservoi

SECTION B
Scale B


450
440
430
420
410
400
390
380
1.5
1
Tailrace Channel El 412.0
Approx original ground
1.0
1
2
Remnant of weir and rockfill dyke
Riprap and bedding
Assumed rock surface

SECTION C
Scale B

LEGEND

Scale B 10

Scale A 20

All dimensi

KEENL

APPR

PLAI

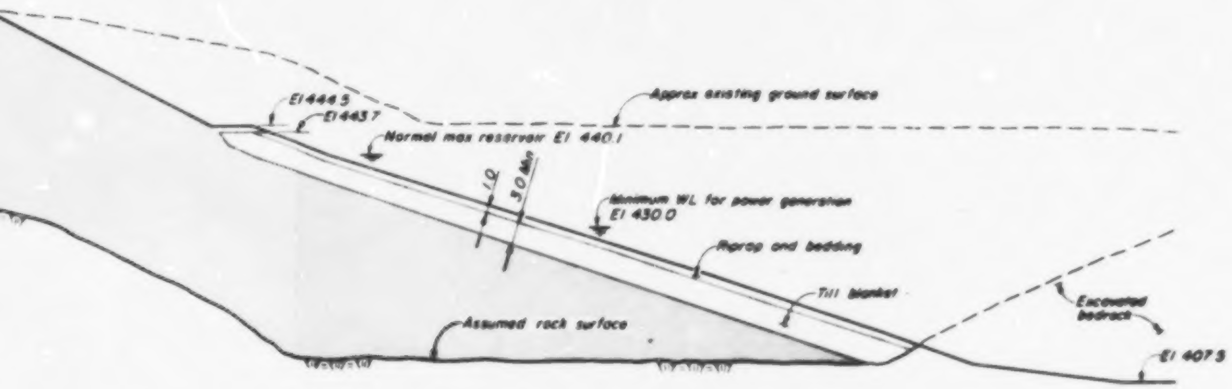
DATE

MA

DWN

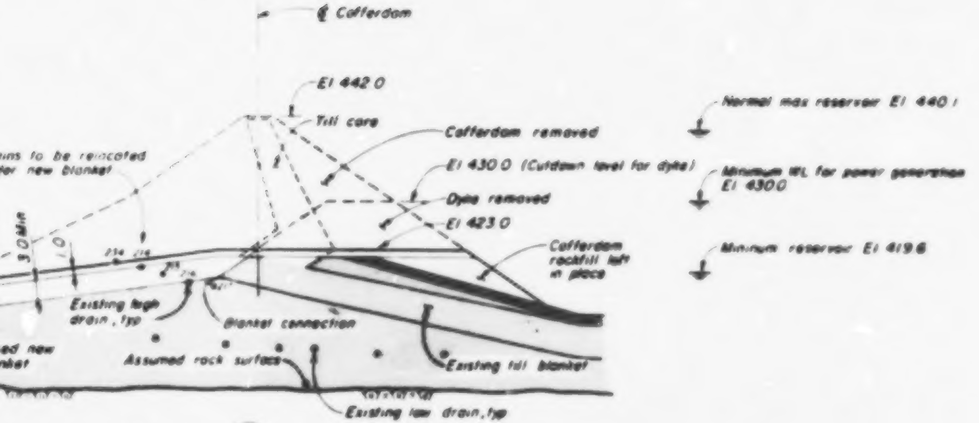
F

REPORT No [illegible]



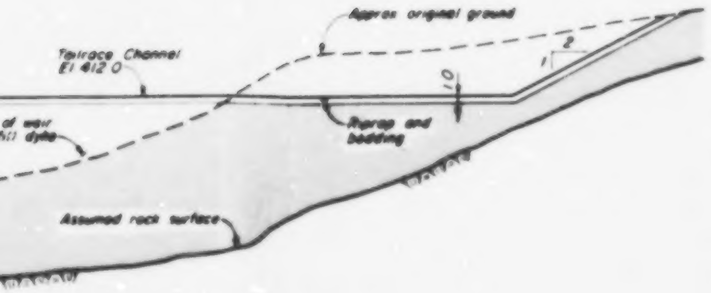
El 444.5
El 443.7
Approx existing ground surface
Normal max reservoir El 440.1
1.0
3.0 Min
Minimum WL for power generation El 430.0
Riprap and bedding
Till blanket
Excavated bedrock
Assumed rock surface
El 407.5

SECTION A
Scale B



℄ Cofferdam
El 442.0
Till core
Cofferdam removed
El 430.0 (Cutdown level for dyke)
Dyke removed
El 423.0
Cofferdam rockfill left in place
Normal max reservoir El 440.1
Minimum WL for power generation El 430.0
Minimum reservoir El 419.6
3.0 Min
1.0
Existing high drain, typ
Blanket connection
Assumed rock surface
Existing till blanket
Existing low drain, typ

SECTION B
Scale B



Approx original ground
Tailrace Channel El 412.0
1.0
2
1
Riprap and bedding
Assumed rock surface

SECTION C
Scale B

LEGEND

APPROXIMATE GROUND CONTOUR

Scale B 10 0 10 20 30 40 Metres

Scale A 20 0 20 40 60 80 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

APPROACH AND TAILRACE CHANNELS
PLAN AND SECTIONS

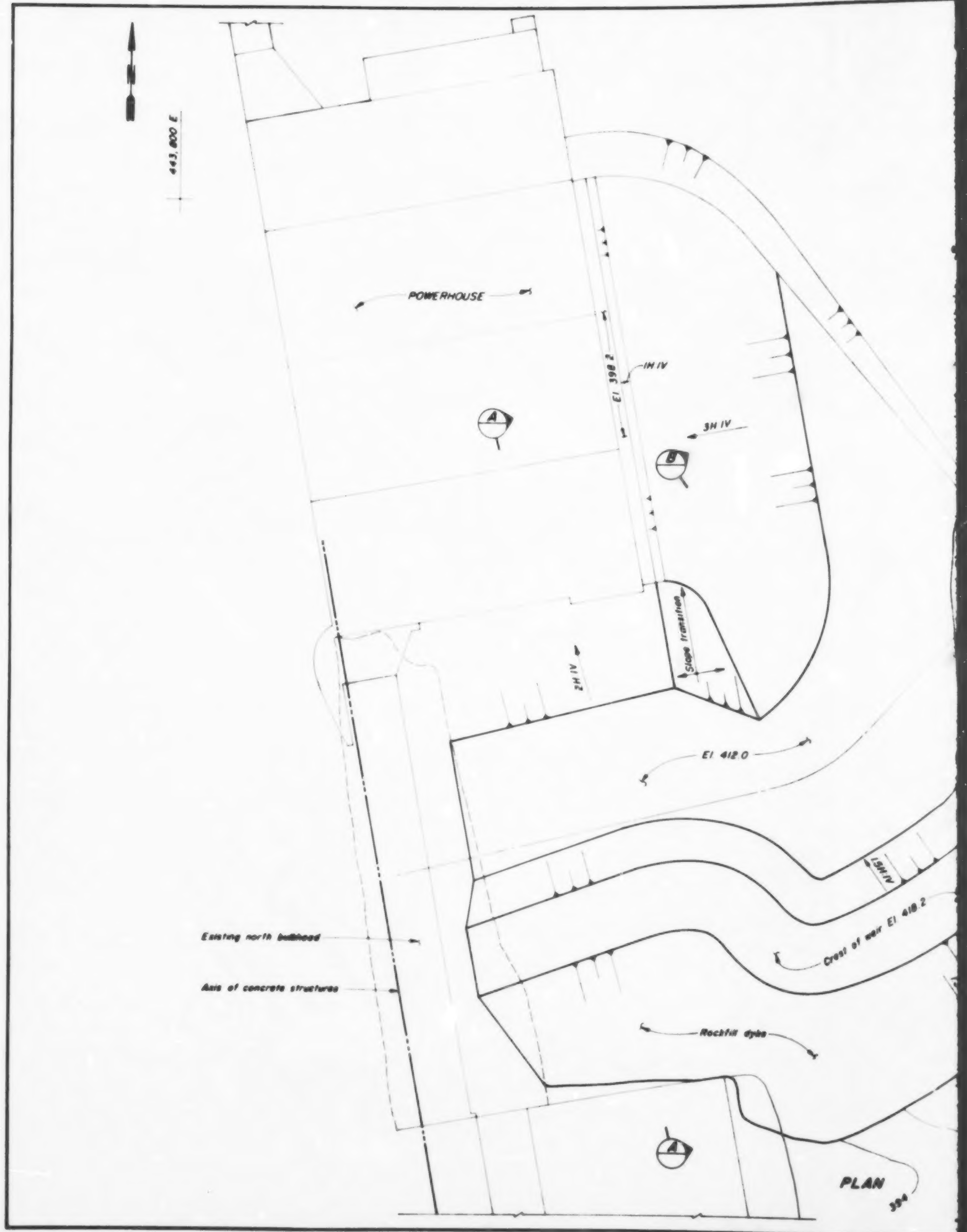
DATE MAY 1983

FIG. 8-8

DWN FL

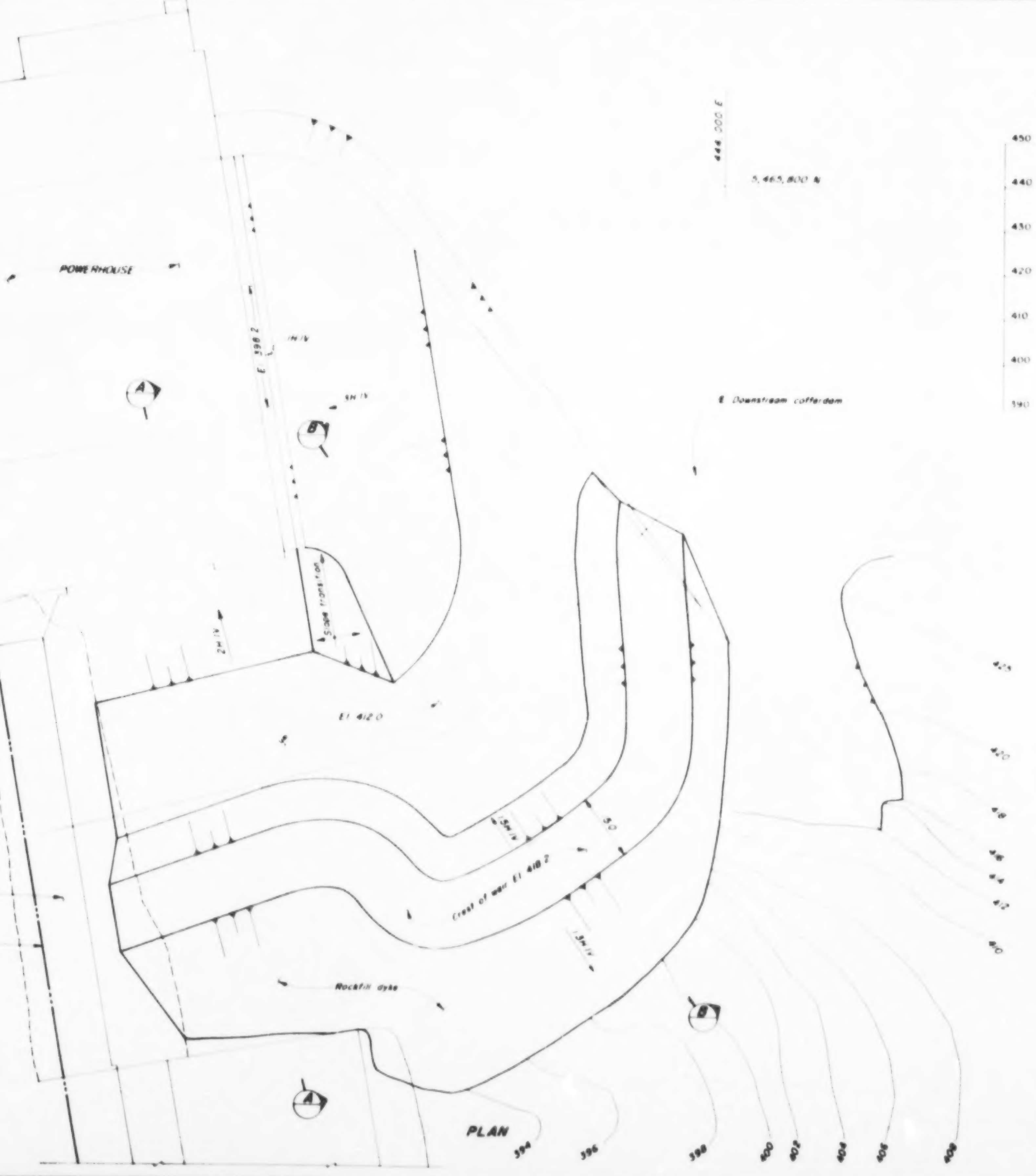
DWG No 240-C14-U305

REPORT No [illegible]

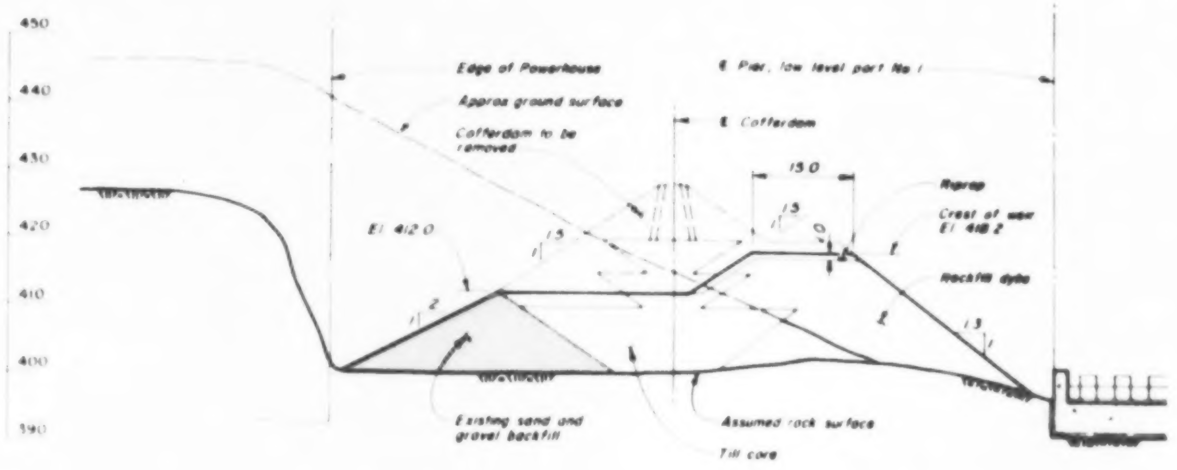


443,800 E
POWERHOUSE
El 398.2
1H 1V
3H 1V
A
B
Slope transition
2H 1V
El 412.0
1.5H 1V
Crest of weir El 418.2
Existing north bulkhead
Axis of concrete structures
Rockfill dyke
394

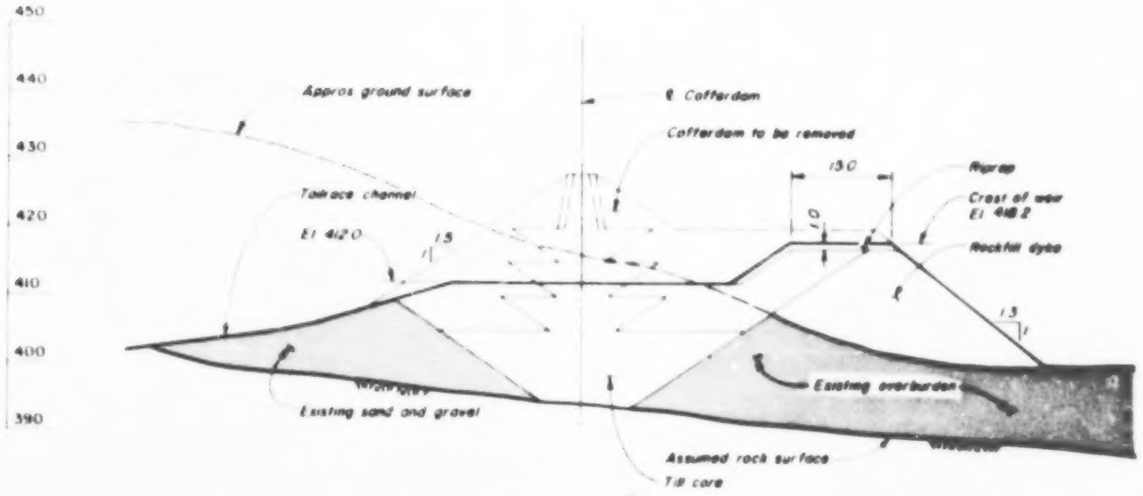
PLAN


POWERHOUSE
444 000 E
5,465,800 N
E 398.2
1H:1V
.5H:1V
Slope transition
2H:1V
℄ Downstream cofferdam
El 412.0
.5H:1V
5.0
Crest of weir El 418.2
1.3H:1V
Rockfill dyke
A
B
394
396
398
400
402
404
406
408
410
412
414
416
418
420
422

PLAN


450
440
430
420
410
400
390
Edge of Powerhouse
℄ Pier, low level port No 1
Approx ground surface
℄ Cofferdam
Cofferdam to be removed
15.0
Riprap
Crest of weir El 418.2
El 412.0
1.5
2
1
1.0
Rockfill dyke
1.3
Existing sand and gravel backfill
Assumed rock surface
Till core

SECTION (A)


450
440
430
420
410
400
390
Approx ground surface
℄ Cofferdam
Cofferdam to be removed
15.0
Riprap
Tailrace channel
Crest of weir El 418.2
El 412.0
1.5
1.0
Rockfill dyke
1.3
Existing overburden
Existing sand and gravel
Assumed rock surface
Till core

SECTION (B)

Scale 10 0 10 20 30 40 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

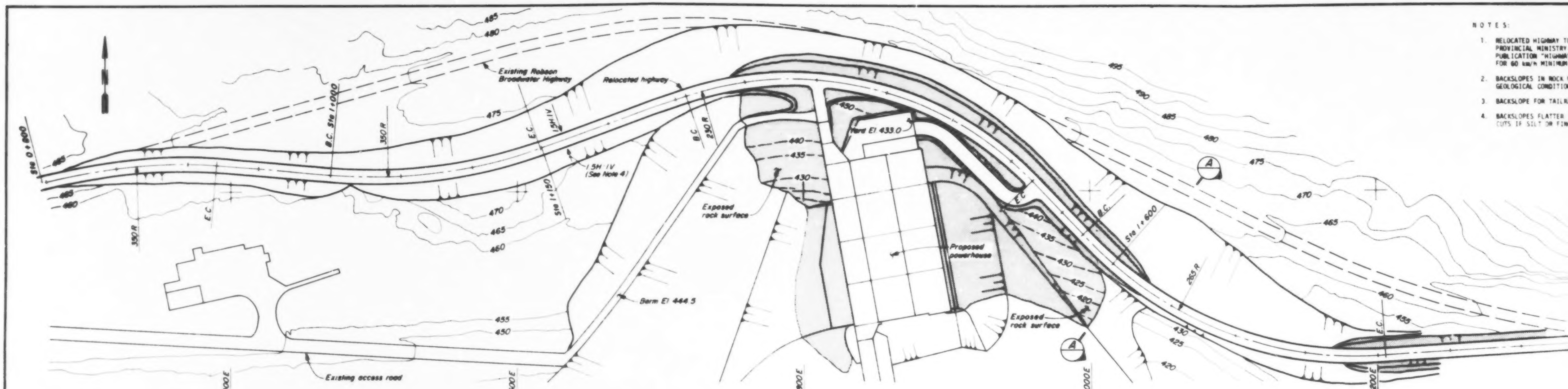
KEENLEYSIDE POWERPLANT PROJECT

TAILRACE WEIR
PLAN AND SECTIONS

DATE MAY 1983	FIG. 8-9
DWN SM	DWG No. 240-C14-U306

REPORT No H1813

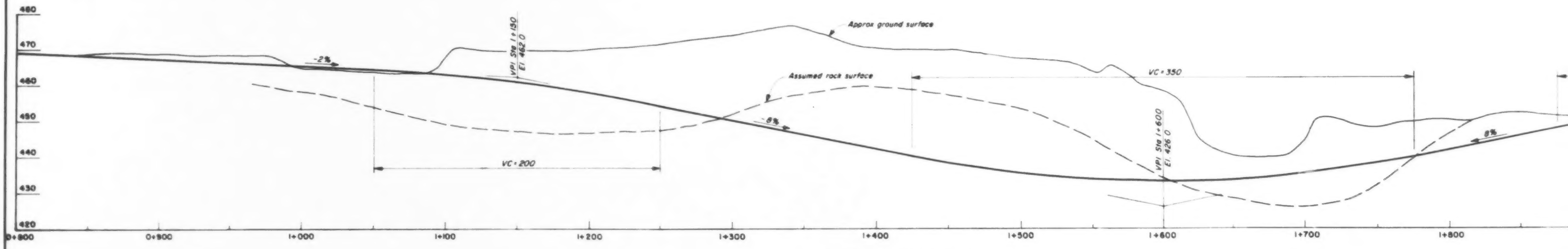
REPORT No. H1613



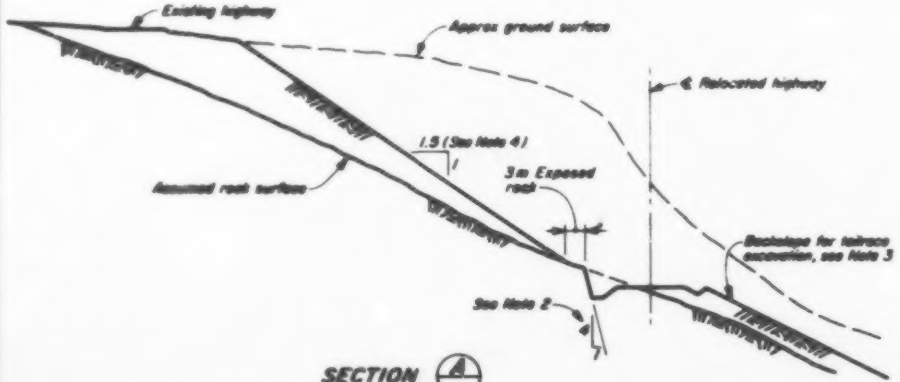
485
480
475
470
465
460
455
450
Existing Robson Broadwater Highway
Relocated highway
Sta 0+800
Sta 1+000
B.C. Sta 1+000
350 R
E.C.
1.5H:1V
1.5H 1V (See Note 4)
Sta 1+150
B.C.
230 R
Yard El 433.0
440
435
430
425
420
Exposed rock surface
Proposed powerhouse
Berm El 444.5
Existing access road
Sta 1+600
265 R
A
443,400 E
443,600 E
443,800 E
444,000 E
444,200 E

PLAN

Scale A



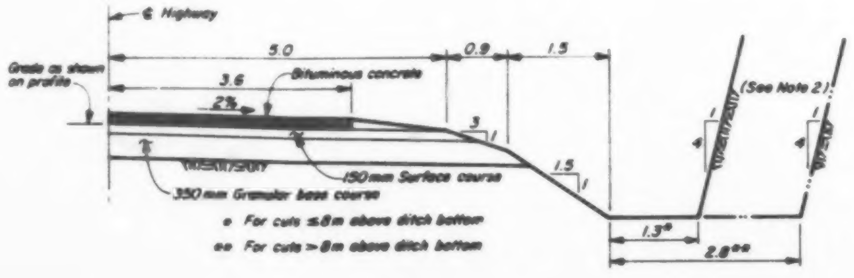
PROFILE ALONG ℄ OF HIGHWAY



Existing highway
Approx ground surface
℄ Relocated highway
1.5 (See Note 4)
1
Assumed rock surface
3m Exposed rock
Backslope for tailrace excavation, see Note 3
See Note 2

SECTION A

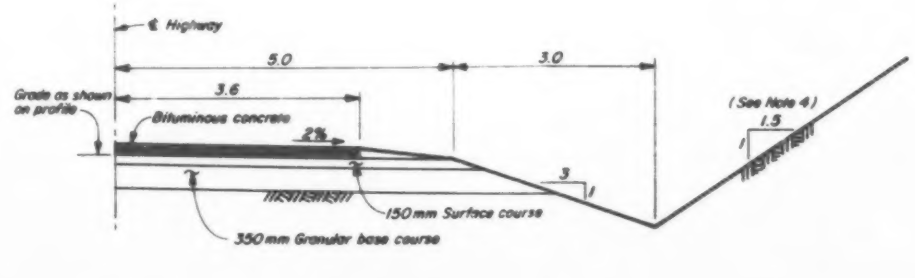
Scale B



℄ Highway
Grade as shown on profile
5.0
3.6
0.9
1.5
2%
Bituminous concrete
3
1
1.5
1
150 mm Surface course
350 mm Granular base course
(See Note 2)
1.3*
2.8**
* For cuts ≤8m above ditch bottom
** For cuts >8m above ditch bottom

TYPICAL ROCK CUT

NTS



℄ Highway
Grade as shown on profile
5.0
3.0
3.6
Bituminous concrete
2%
3
1
150 mm Surface course
350 mm Granular base course
(See Note 4)
1.5
1

TYPICAL OVERBURDEN CUT

NTS

NOTES:

1. RELOCATED HIGHWAY T
PROVINCIAL MINISTRY
PUBLICATION "HIGHWA
FOR 60 km/h MINIMUM

2. BACKSLOPES IN ROCK
GEOLOGICAL CONDITIO

3. BACKSLOPE FOR TAILR

4. BACKSLOPES FLATTER
CUTS IF SILT OR FIN

Scale B 1
Scale A 2

All dimens

BRITIS

KEENLEYSID

HIGHWAY

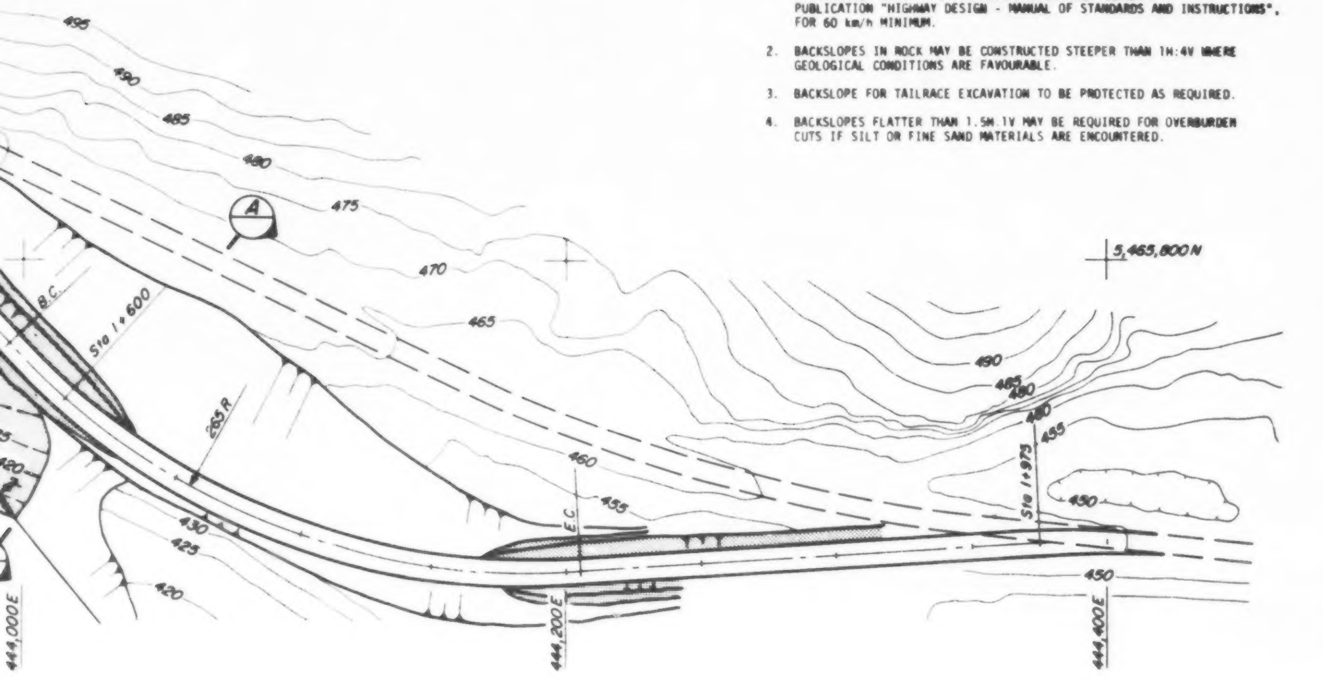
PLAN, P

DATE
MAY 19

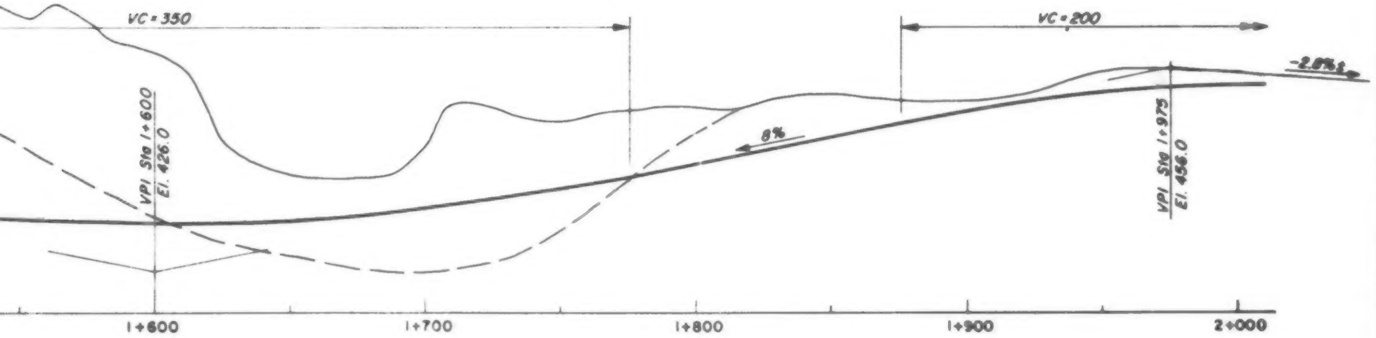
DWN
AV

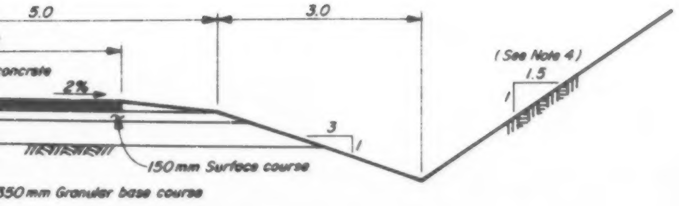
NOTES:

1. RELOCATED HIGHWAY TO BE DESIGNED IN ACCORDANCE WITH THE B.C. PROVINCIAL MINISTRY OF TRANSPORTATION AND HIGHWAYS' PUBLICATION "HIGHWAY DESIGN - MANUAL OF STANDARDS AND INSTRUCTIONS", FOR 60 km/h MINIMUM.
2. BACKSLOPES IN ROCK MAY BE CONSTRUCTED STEEPER THAN 1H:4V WHERE GEOLOGICAL CONDITIONS ARE FAVOURABLE.
3. BACKSLOPE FOR TAILRACE EXCAVATION TO BE PROTECTED AS REQUIRED.
4. BACKSLOPES FLATTER THAN 1.5H.1V MAY BE REQUIRED FOR OVERBURDEN CUTS IF SILT OR FINE SAND MATERIALS ARE ENCOUNTERED.



495
490
485
480
475
470
465
460
455
450
430
425
420
A
B.C.
Sta 1+600
255 R
E.C.
Sta 1+973
5,465,800 N
444,000E
444,200E
444,400E





5.0
3.0
concrete
2%
(See Note 4)
1.5
1
3
1
150mm Surface course
350mm Granular base course

TYPICAL OVERBURDEN CUT

NTS

Scale: B 10 0 10 20 30 40 Metres

Scale: A 25 0 25 50 75 100 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

HIGHWAY RELOCATION
PLAN, PROFILE AND SECTIONS

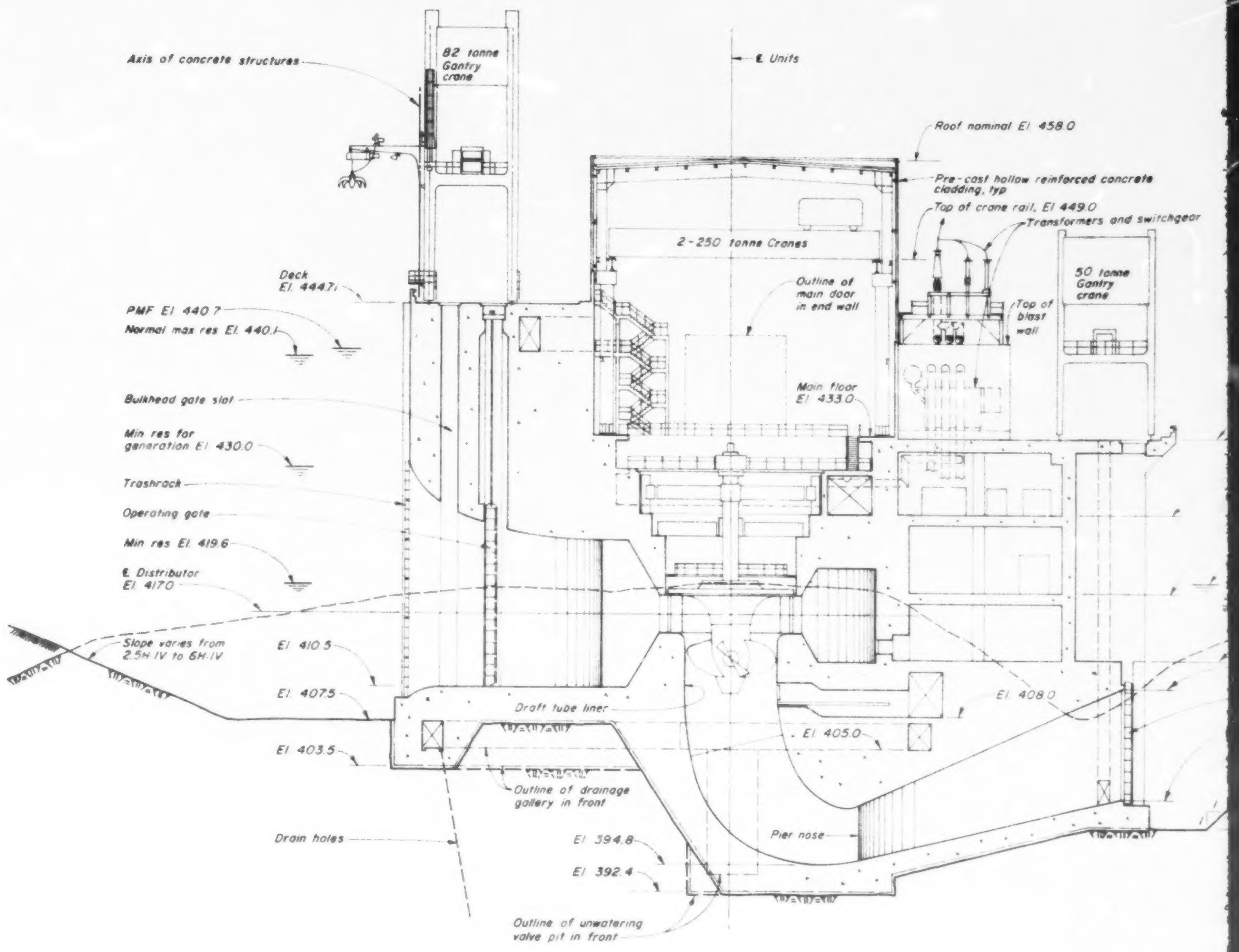
DATE MAY 1983

FIG. 8-10

DWN AV

DWG No. 240-C14-U307

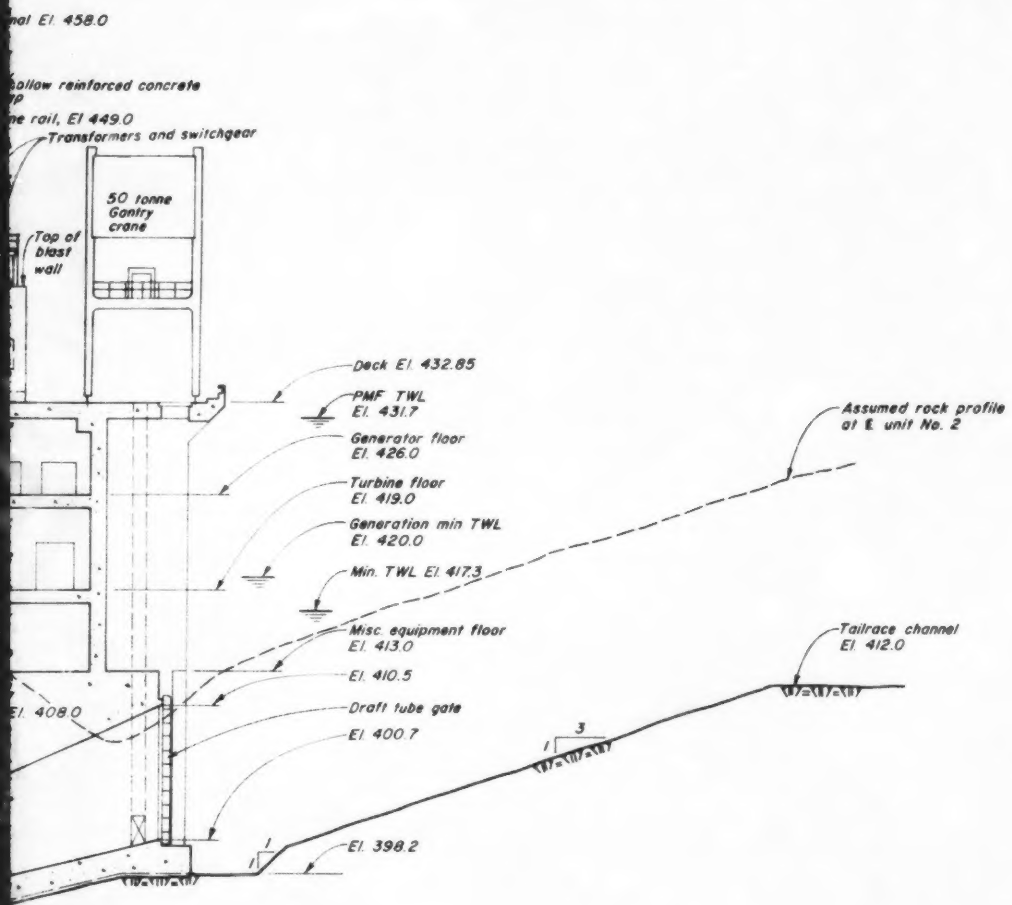
REPORT No H1613



Axis of concrete structures
82 tonne Gantry crane
℄ Units
Roof nominal El. 458.0
Pre-cast hollow reinforced concrete cladding, typ
Top of crane rail, El. 449.0
Transformers and switchgear
2-250 tonne Cranes
50 tonne Gantry crane
Top of blast wall
Outline of main door in end wall
Deck El. 444.7
PMF El. 440.7
Normal max res El. 440.1
Main floor El. 433.0
Bulkhead gate slot
Min res for generation El. 430.0
Trashrack
Operating gate
Min res El. 419.6
℄ Distributor El. 417.0
Slope varies from 2.5H:1V to 6H:1V
El. 410.5
El. 407.5
El. 403.5
Draft tube liner
Outline of drainage gallery in front
El. 405.0
El. 408.0
Drain holes
El. 394.8
El. 392.4
Pier nose
Outline of unwatering valve pit in front

SECTION (A / 8-13)

(AT ℄ UNIT 2)


nal El. 458.0
hollow reinforced concrete
yp
ne rail, El 449.0
Transformers and switchgear
50 tonne Gantry crane
Top of blast wall
Deck El. 432.85
PMF TWL El. 431.7
Generator floor El. 426.0
Turbine floor El. 419.0
Generation min TWL El. 420.0
Min. TWL El. 417.3
Misc. equipment floor El. 413.0
El. 410.5
Draft tube gate
El. 400.7
El. 408.0
El. 398.2
1
1
1
3
Assumed rock profile at ℄ unit No. 2
Tailrace channel El. 412.0

Scale: 0 5 10 15 20 25 Metres

All dimensions are in metres, unless otherwise shown

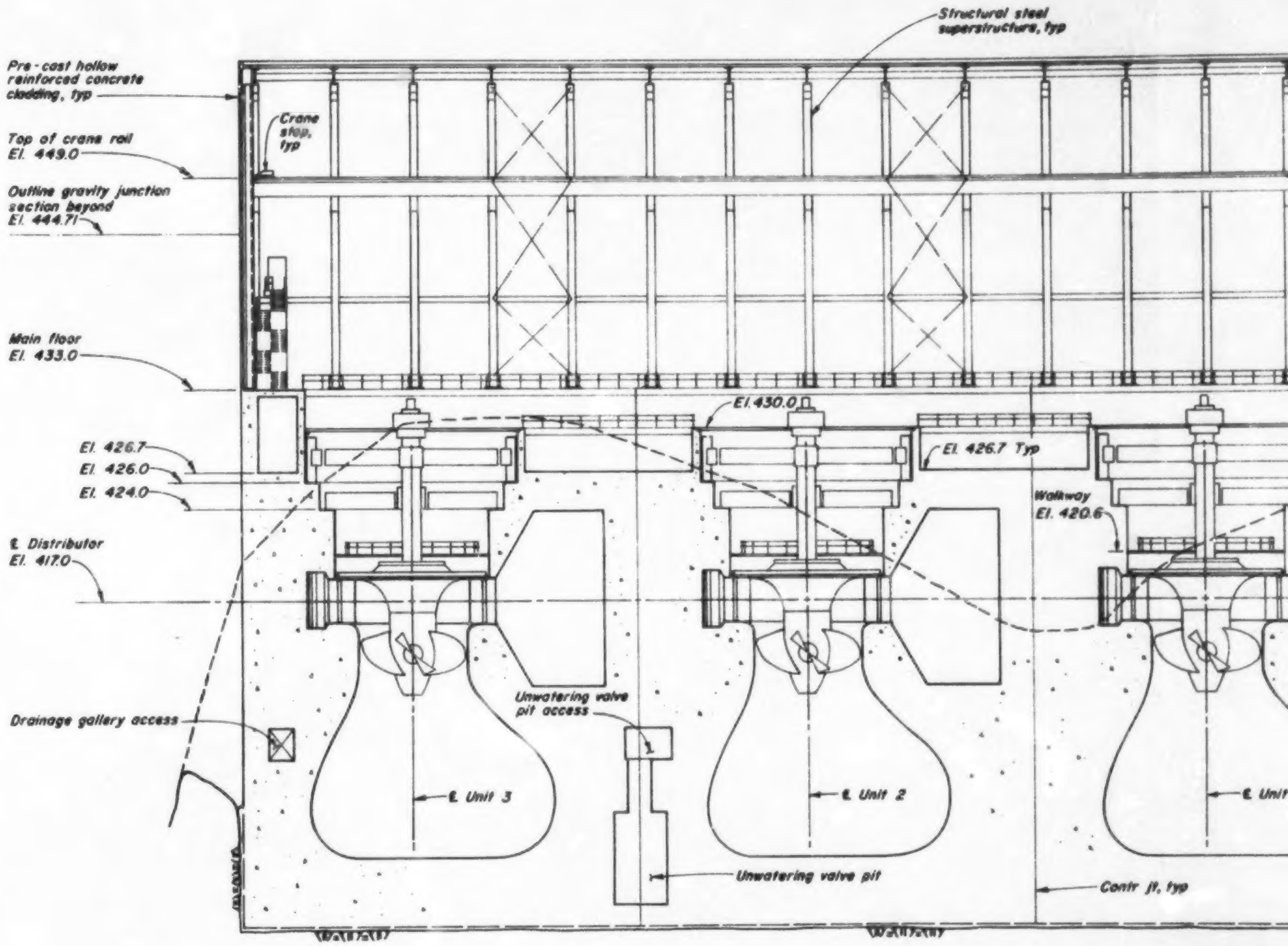
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

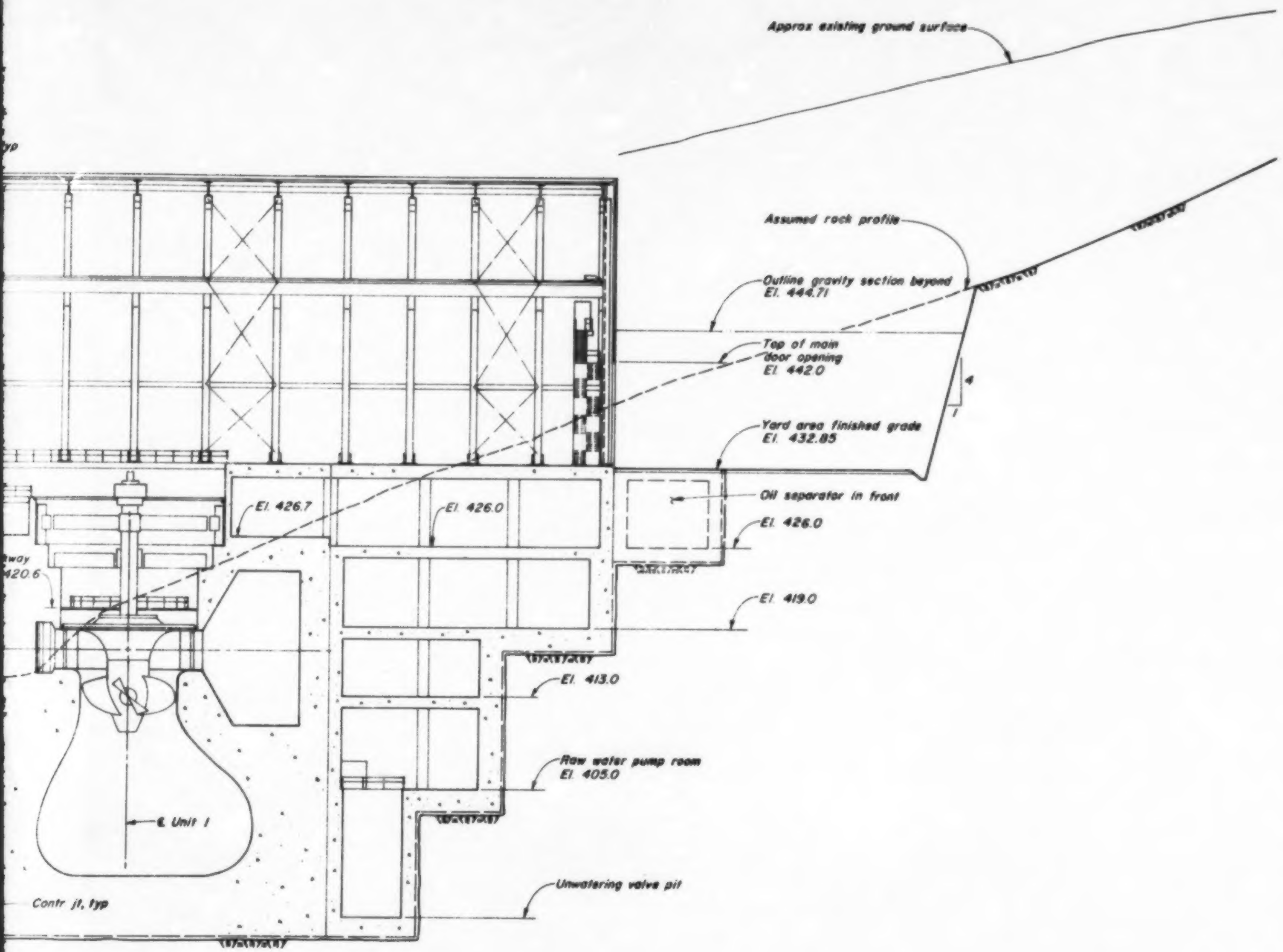
POWERHOUSE
SECTION AT CENTRELINE UNIT 2

DATE MAY 1983 | FIG. 8-11 | R
DWN SM | DWG No. 240-C14-D308

REPORT No. H1613


Structural steel superstructure, typ
Pre-cast hollow reinforced concrete cladding, typ
Crane stop, typ
Top of crane rail El. 449.0
Outline gravity junction section beyond El. 444.71
Main floor El. 433.0
El. 430.0
El. 426.7
El. 426.0
El. 424.0
El. 426.7 Typ
Walkway El. 420.6
℄ Distributor El. 417.0
Drainage gallery access
Unwatering valve pit access
℄ Unit 3
℄ Unit 2
℄ Unit
Unwatering valve pit
Contr jt, typ

LONGITUDINAL SECTION
(AT ℄ UNITS)


typ
way
420.6
Approx existing ground surface
Assumed rock profile
Outline gravity section beyond
El. 444.71
Top of main
door opening
El. 442.0
4
1
Yard area finished grade
El. 432.85
El. 426.7
El. 426.0
Oil separator in front
El. 426.0
El. 419.0
El. 413.0
Raw water pump room
El. 405.0
℄ Unit 1
Unwatering valve pit
Contr jt, typ

Scale: 0 5 10 15 20 25 Metres

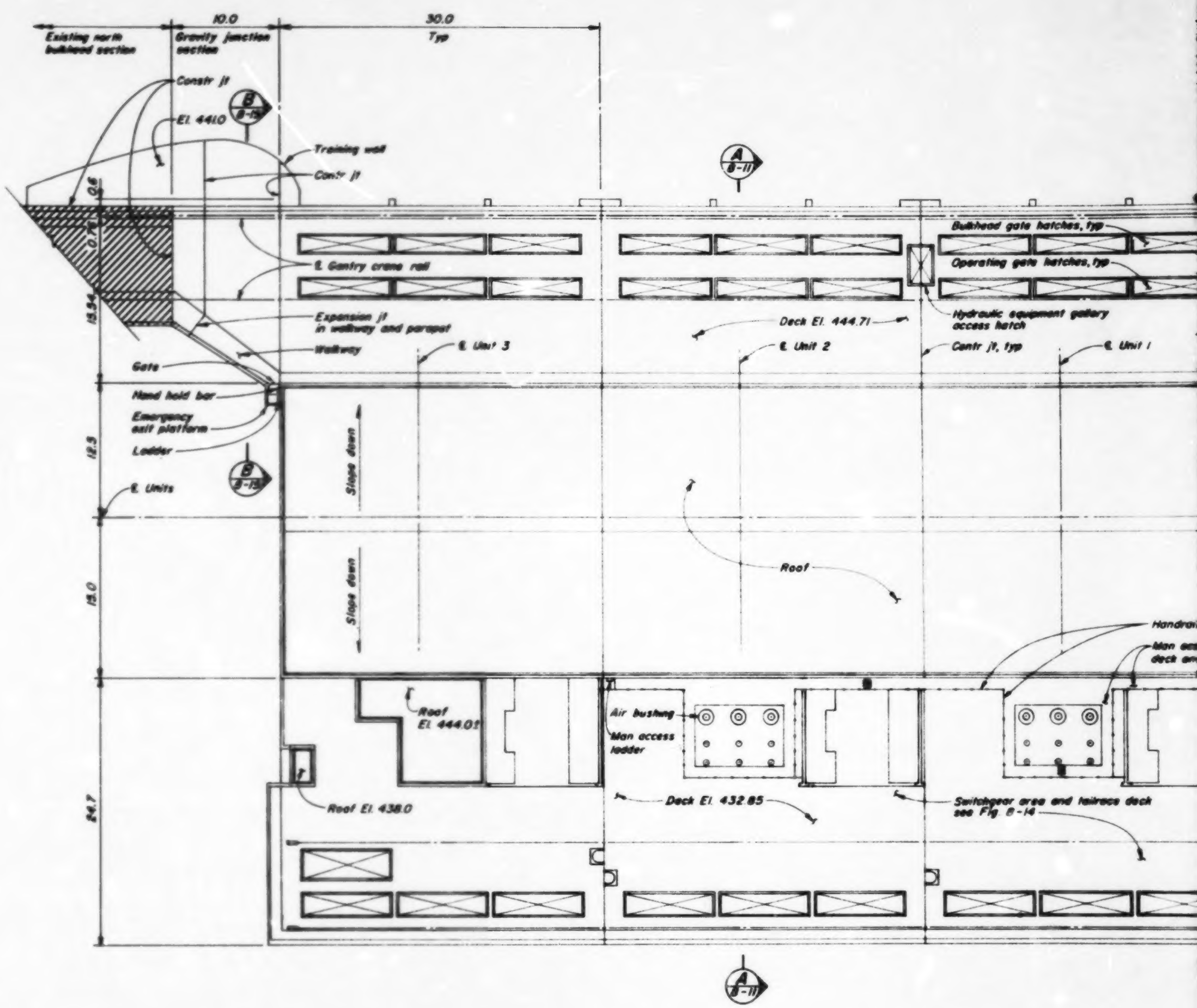
All dimensions are in metres, unless otherwise shown

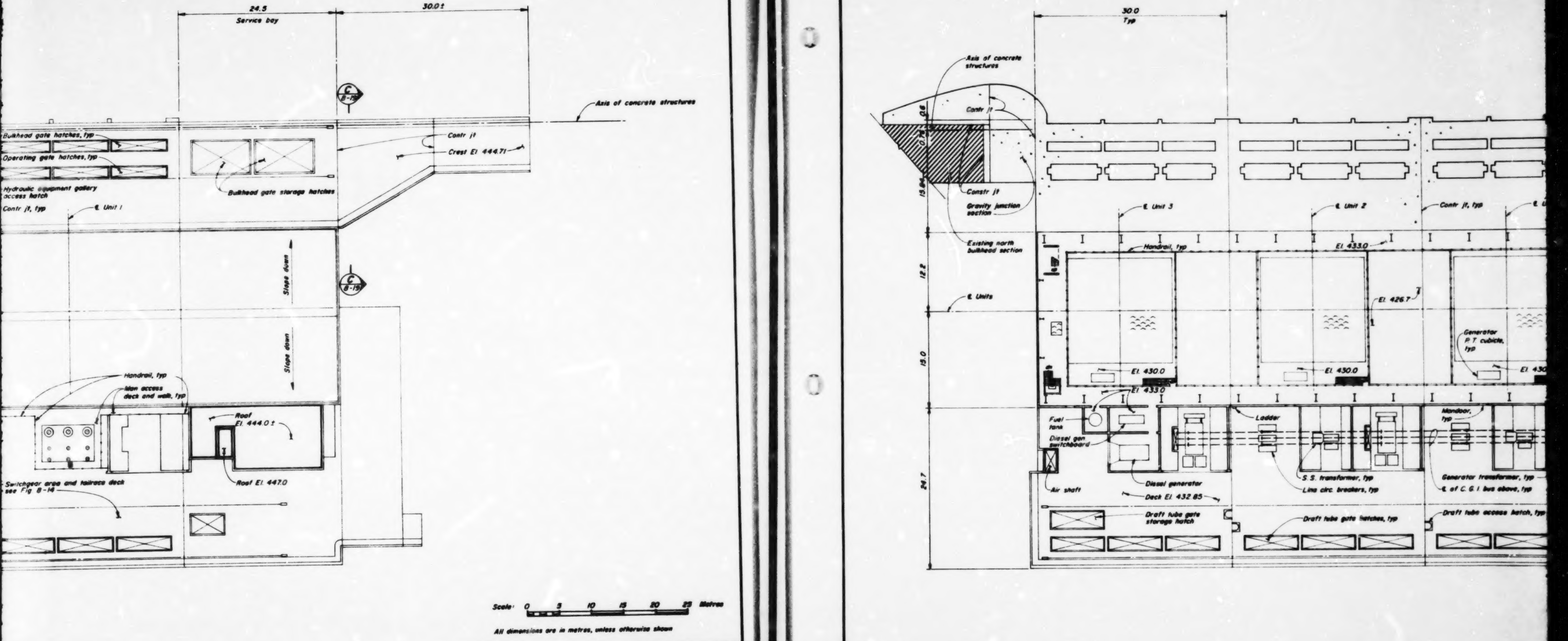
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
POWERHOUSE
LONGITUDINAL SECTION AT CENTRELINE UNITS

DATE MAY 1983	FIG. 8-12	R
DWN SM	DWG No. 240-C14-D309	

REPORT No. H1613


10.0
30.0
Typ
Existing north
bulkhead section
Gravity junction
section
Constr jt
B
8-15
El. 441.0
Training wall
Contr jt
0.6
0.76
15.54
12.5
15.0
24.7
A
8-11
℄ Gantry crane rail
Expansion jt
in walkway and parapet
Walkway
Gate
Hand hold bar
Emergency
exit platform
Ladder
℄ Units
Slope down
Slope down
℄ Unit 3
Deck El. 444.71
℄ Unit 2
Bulkhead gate hatches, typ
Operating gate hatches, typ
Hydraulic equipment gallery
access hatch
Contr jt, typ
℄ Unit 1
Roof
Handrai
Man acc
deck an
Roof
El. 444.05
Roof El. 438.0
Air bushing
Man access
ladder
Deck El. 432.85
Switchgear area and tailrace deck
see Fig. 8-14


24.5
Service bay
30.0±
Axis of concrete structures
Bulkhead gate hatches, typ
Operating gate hatches, typ
Hydraulic equipment gallery access hatch
Contr jt, typ
℄ Unit 1
Bulkhead gate storage hatches
Contr jt
Crest El 444.71
C 8-15
Slope down
Slope down
Handrail, typ
Man access deck and walk, typ
Roof El. 444.0 ±
Roof El 447.0
Switchgear area and tailrace deck see Fig 8-14
30.0
Typ
Axis of concrete structures
Contr jt
Constr jt
Gravity junction section
Existing north bulkhead section
℄ Unit 3
℄ Unit 2
Contr jt, typ
℄ Units
Handrail, typ
El. 433.0
El. 426.7
Generator P.T. cubicle, typ
El. 430.0
El. 430.0
El. 433.0
Fuel tank
Diesel gen switchboard
Air shaft
Diesel generator
Deck El. 432.85
Ladder
S. S. transformer, typ
Line circ. breakers, typ
Mandoor, typ
Generator transformer, typ
℄ of C. G. I. bus above, typ
Draft tube gate storage hatch
Draft tube gate hatches, typ
Draft tube access hatch, typ
12.2
15.0
24.7
Scale: 0 5 10 15 20 25 Metres

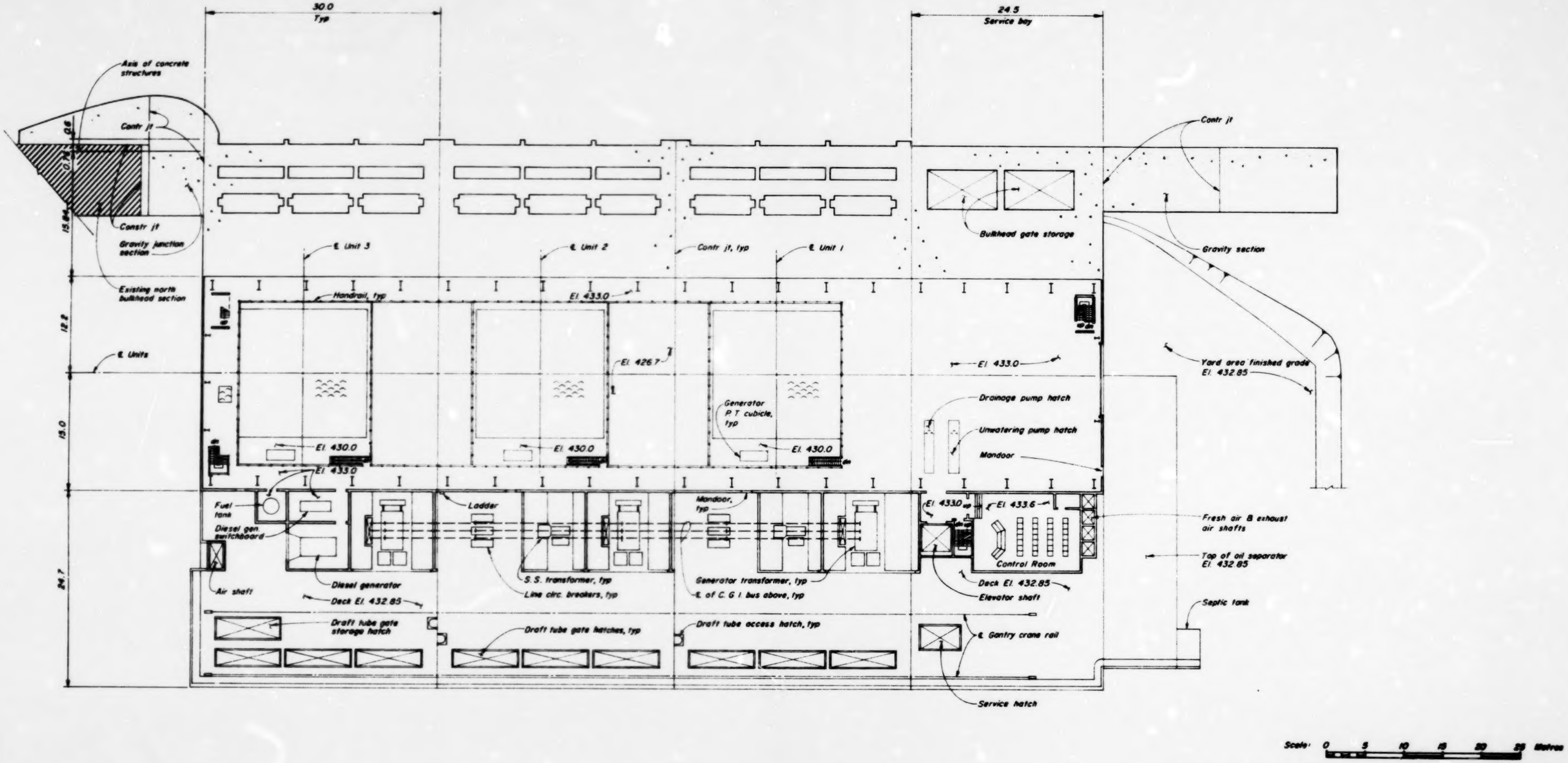
All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
POWERHOUSE
ROOF AND DECKS
PLAN

DATE MAY 1983	FIG. 8-13		R
DWN SM	DWG No.	240-C14-D310	

REPORT No. H1613


30.0
Typ
24.5
Service bay
Axis of concrete structures
Contr jt
0.6
0.76
15.84
Constr jt
Gravity junction section
Existing north bulkhead section
℄ Unit 3
℄ Unit 2
Contr jt, typ
℄ Unit 1
Contr jt
Bulkhead gate storage
Gravity section
Handrail, typ
El. 433.0
12.2
℄ Units
El. 426.7
El. 433.0
Yard area finished grade
El. 432.85
Generator P.T. cubicle, typ
Drainage pump hatch
Unwatering pump hatch
Mandoor
15.0
El. 430.0
El. 430.0
El. 430.0
El. 433.0
Fuel tank
Diesel gen. switchboard
Ladder
Mandoor, typ
El. 433.0
El. 433.6
Fresh air & exhaust air shafts
Control Room
Top of oil separator
El. 432.85
24.7
Air shaft
Diesel generator
Deck El. 432.85
S. S. transformer, typ
Line circ. breakers, typ
Generator transformer, typ
℄ of C. G. I. bus above, typ
Deck El. 432.85
Elevator shaft
Septic tank
Draft tube gate storage hatch
Draft tube gate hatches, typ
Draft tube access hatch, typ
℄ Gantry crane rail
Service hatch
Scale: 0 5 10 15 20 25 Metres

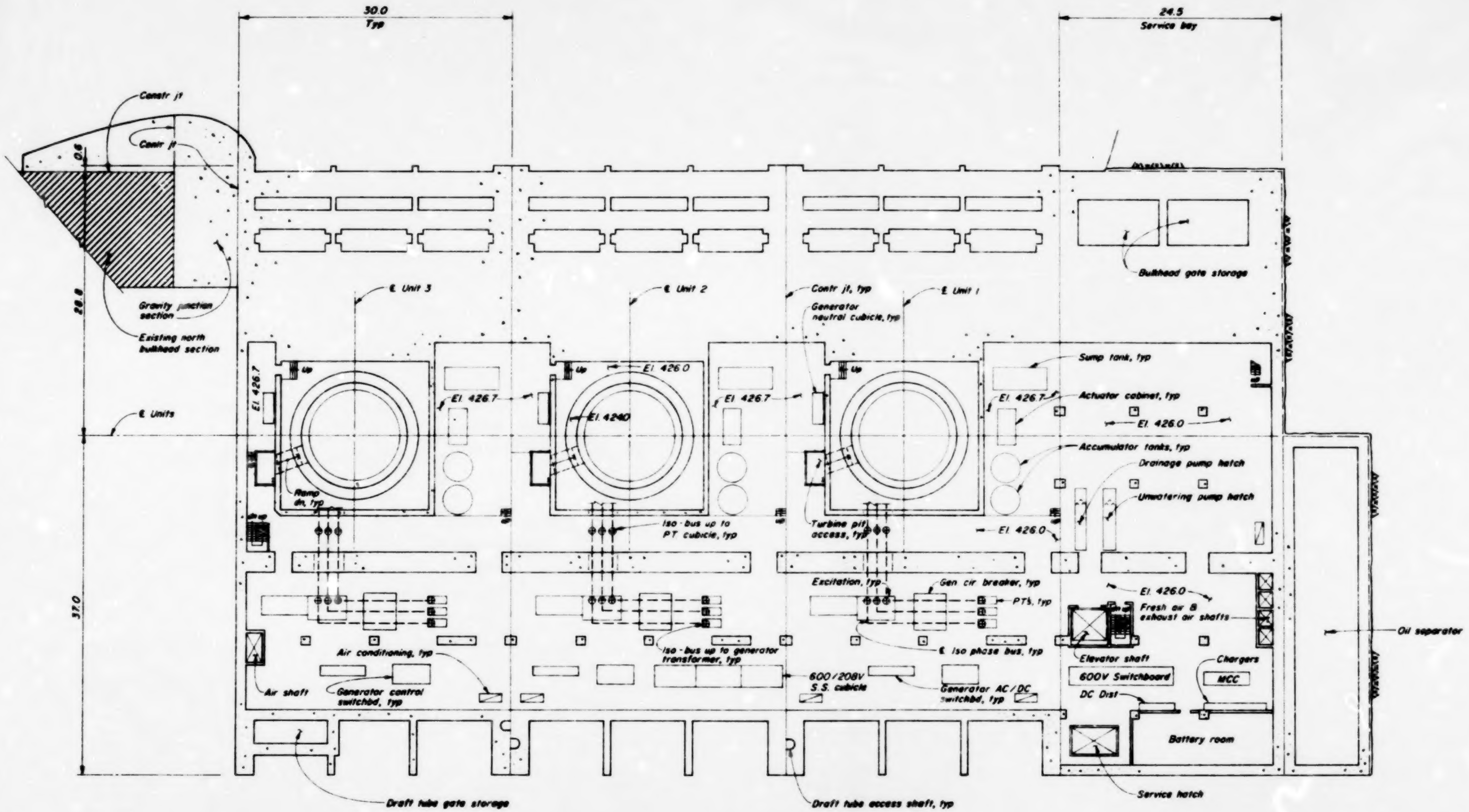
All dimensions are in metres, unless otherwise shown

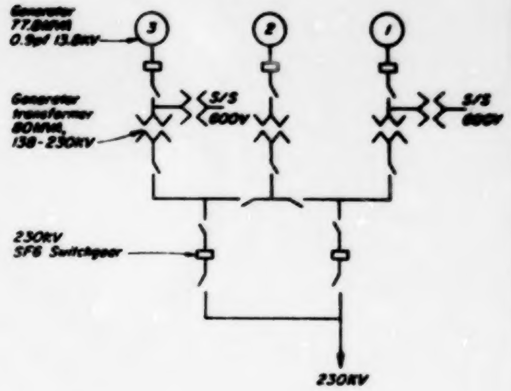
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
POWERHOUSE
MAIN FLOOR
PLAN EL. 433.0

DATE MAY 1983
FIG. 8-14
R
DWN SM
DWG No. 240-C14-D311

REPORT No. H1683


30.0
Typ
24.5
Service bay
Constr jt
Constr jt
0.6
28.8
37.0
Gravity junction section
Existing north bulkhead section
℄ Units
℄ Unit 3
℄ Unit 2
℄ Unit 1
Contr jt, typ
Generator neutral cubicle, typ
Bulkhead gate storage
Sump tank, typ
Actuator cabinet, typ
Accumulator tanks, typ
Drainage pump hatch
Unwatering pump hatch
El. 426.7
El. 426.7
El. 426.7
El. 426.7
El. 426.0
El. 424.0
El. 426.0
El. 426.0
El. 426.0
Up
Up
Up
Ramp dn, typ
Iso-bus up to PT cubicle, typ
Turbine pit access, typ
Excitation, typ
Gen cir breaker, typ
PT's, typ
Fresh air & exhaust air shafts
Oil separator
Air conditioning, typ
Iso-bus up to generator transformer, typ
℄ Iso phase bus, typ
Elevator shaft
Chargers
600V Switchboard
MCC
Air shaft
Generator control switchbd, typ
600/208V S.S. cubicle
Generator AC/DC switchbd, typ
DC Dist
Battery room
Draft tube gate storage
Draft tube access shaft, typ
Service hatch


Generator 77.8MVA 0.9pf 13.8KV
3
2
1
Generator transformer 80MVA, 13.8-230KV
S/S 600V
S/S 600V
230KV SF6 Switchgear
230KV

SINGLE LINE DIAGRAM

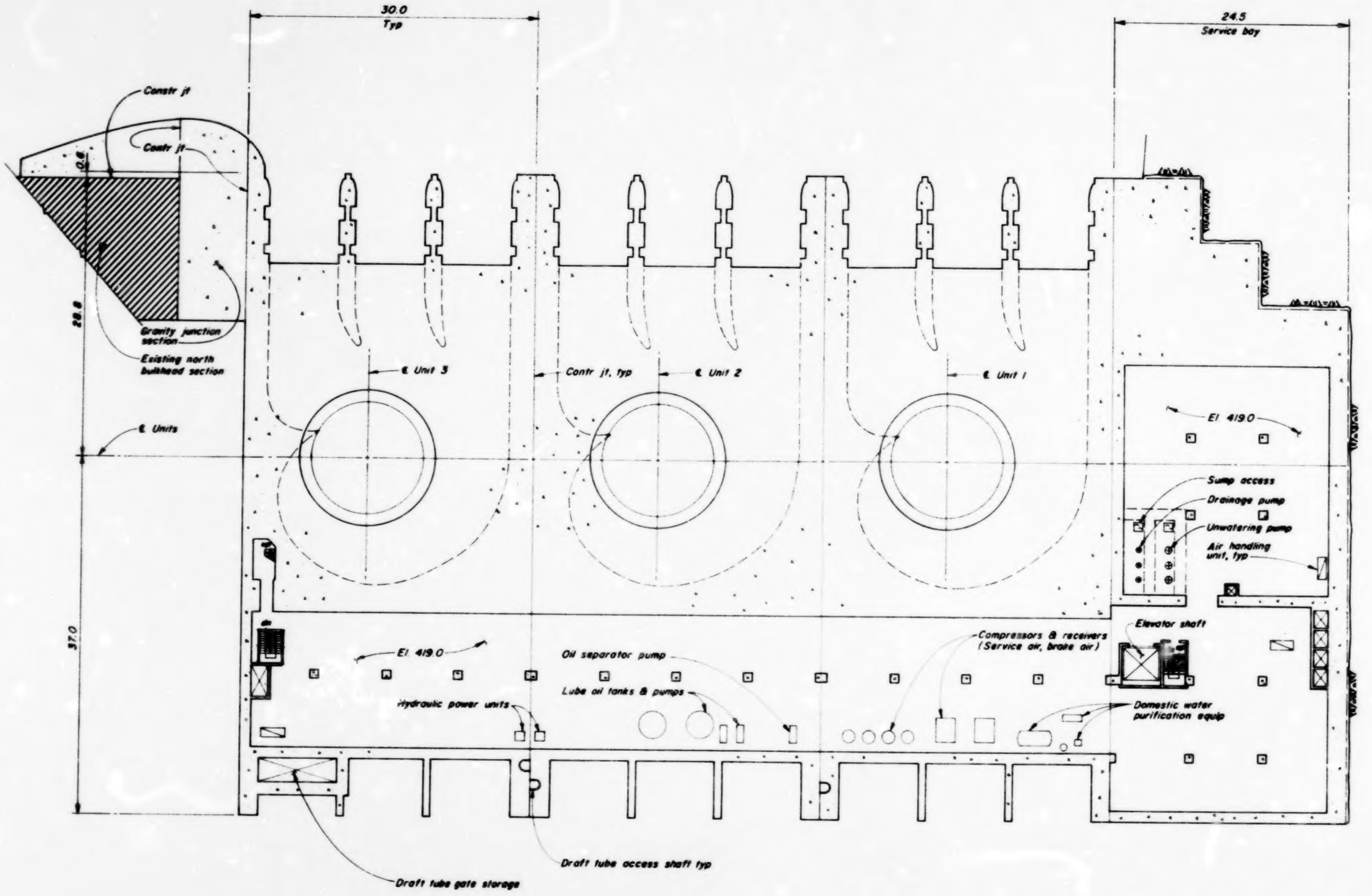
Scale: 0 5 10 15 20 25 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
POWERHOUSE
GENERATOR FLOOR
PLAN EL. 426.0

DATE MAY 1983
FIG. 8-15
R
SM
DWG No. 240-C14-D312


30.0
Typ
24.5
Service bay
Constr jt
Contr jt
0.6
28.8
Gravity junction section
Existing north bulkhead section
℄ Unit 3
Contr jt, typ
℄ Unit 2
℄ Unit 1
℄ Units
El 419.0
Sump access
Drainage pump
Unwatering pump
Air handling unit, typ
Elevator shaft
Compressors & receivers (Service air, brake air)
El 419.0
Oil separator pump
Lube oil tanks & pumps
Hydraulic power units
Domestic water purification equip
37.0
Draft tube gate storage
Draft tube access shaft typ

Scale: 0 5 10 15 20 25 Metres

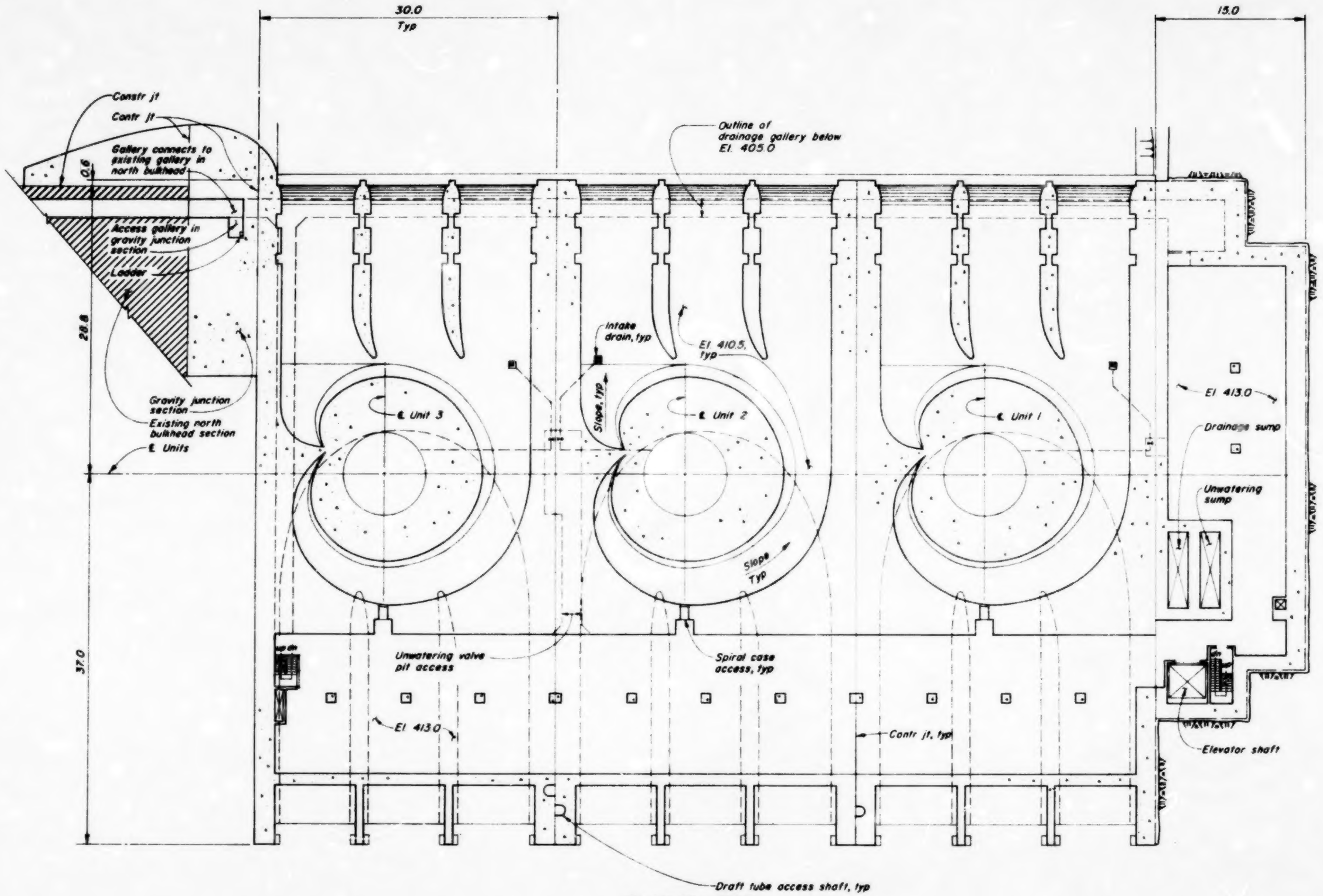
All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

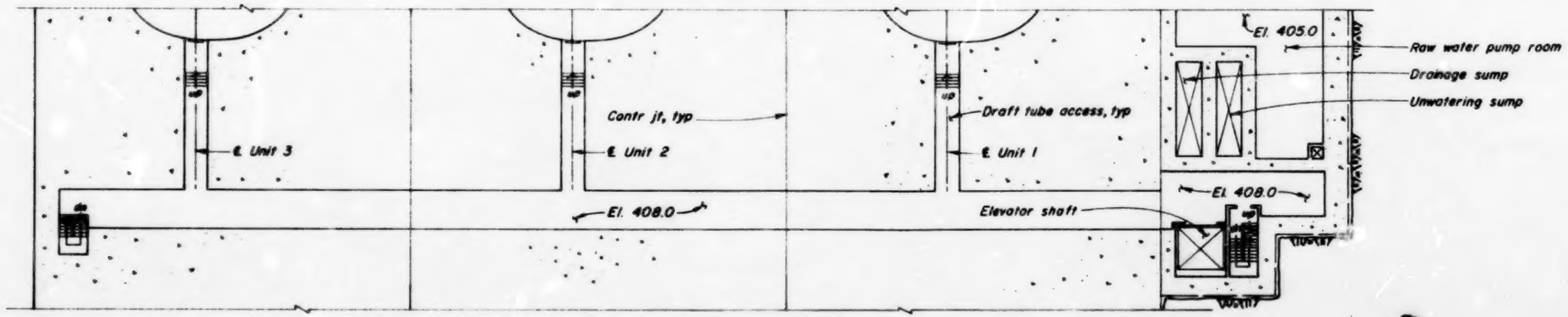
KEENLEYSIDE POWERPLANT PROJECT
POWERHOUSE
TURBINE FLOOR
PLAN EL. 419.0

DATE MAY 1983	FIG. 8-16	R
DWN SM	DWG No. 240-C14-D313	

REPORT No. H1613


30.0
Typ
15.0
Constr jt
Contr jt
Gallery connects to existing gallery in north bulkhead
0.6
Access gallery in gravity junction section
Ladder
28.8
Gravity junction section
Existing north bulkhead section
℄ Units
37.0
Outline of drainage gallery below El. 405.0
Intake drain, typ
Slope, typ
El. 410.5, typ
℄ Unit 3
℄ Unit 2
℄ Unit 1
Slope Typ
El. 413.0
Drainage sump
Unwatering sump
Unwatering valve pit access
Spiral case access, typ
El. 413.0
Contr jt, typ
Elevator shaft
Draft tube access shaft, typ

PLAN EL. 413.0


El. 405.0
Raw water pump room
Drainage sump
Unwatering sump
Contr jt, typ
Draft tube access, typ
℄ Unit 3
℄ Unit 2
℄ Unit 1
El. 408.0
El. 408.0
Elevator shaft

PLAN EL. 408.0

Scale: 0 5 10 15 20 25 Metres

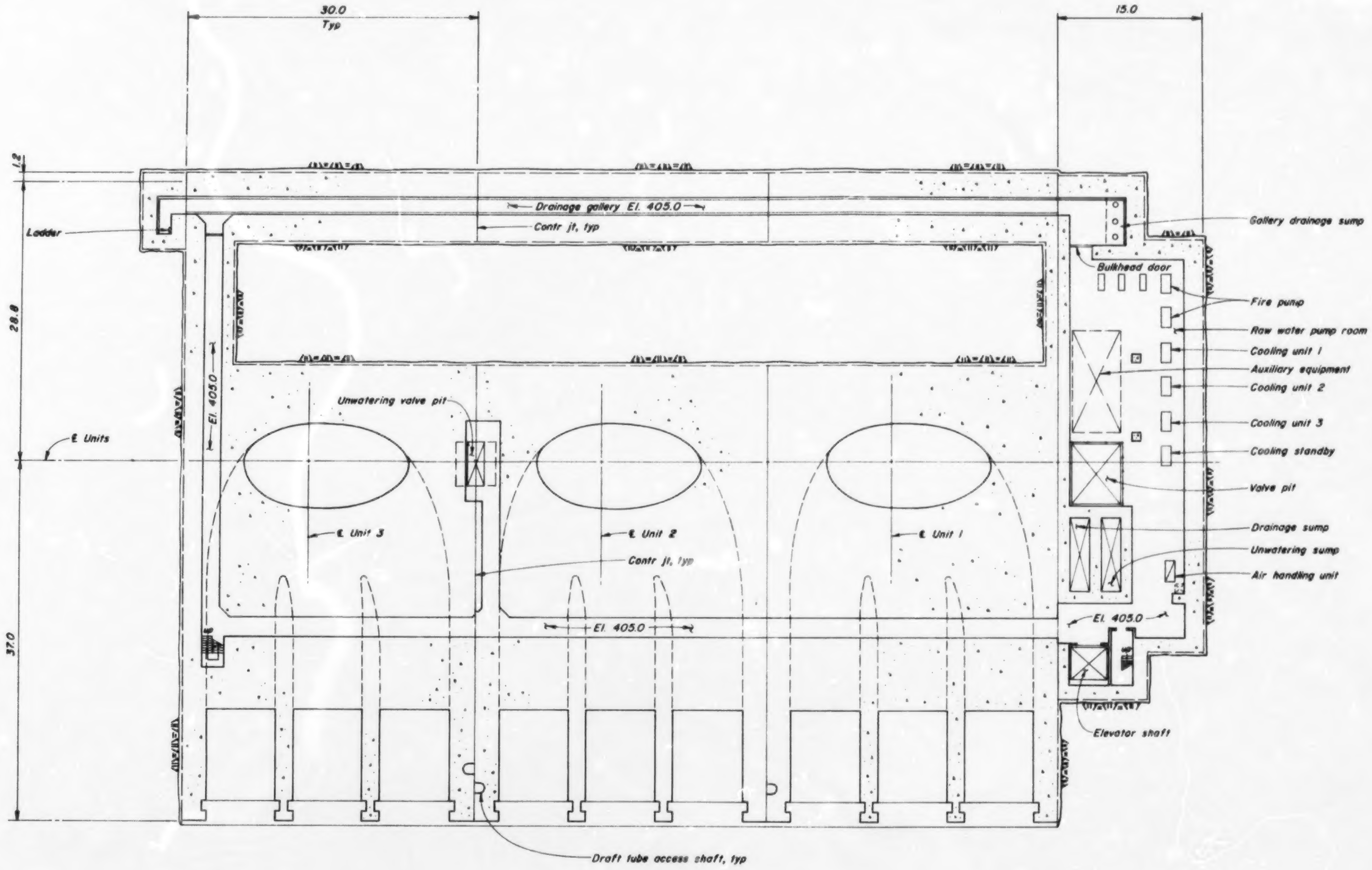
All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
POWERHOUSE
MISC. EQUIPMENT FLOOR
PLAN EL. 413.0 & 408.0

DATE MAY 1983	FIG. 8-17	R
DWN SM	DWG No. 240-C14-D314	

REPORT No. H1613


30.0
Typ
15.0
1.2
28.8
37.0
Ladder
Drainage gallery El. 405.0
Contr jt, typ
Gallery drainage sump
Bulkhead door
Fire pump
Raw water pump room
Cooling unit 1
Auxiliary equipment
Cooling unit 2
Cooling unit 3
Cooling standby
Valve pit
Drainage sump
Unwatering sump
Air handling unit
El. 405.0
Unwatering valve pit
℄ Units
℄ Unit 3
℄ Unit 2
℄ Unit 1
Contr jt, typ
El. 405.0
El. 405.0
Elevator shaft
Draft tube access shaft, typ

Scale: 0 5 10 15 20 25 Metres

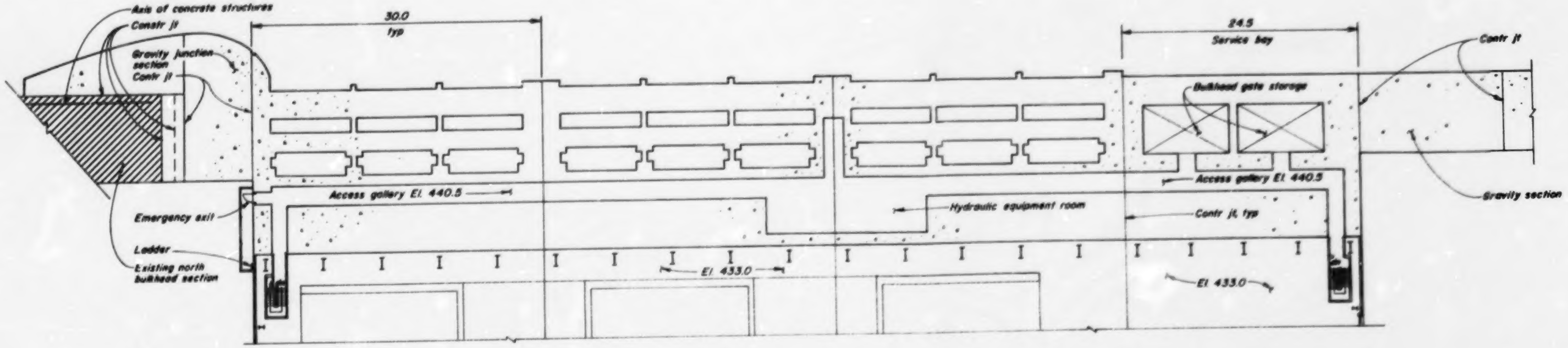
All dimensions are in metres, unless otherwise shown

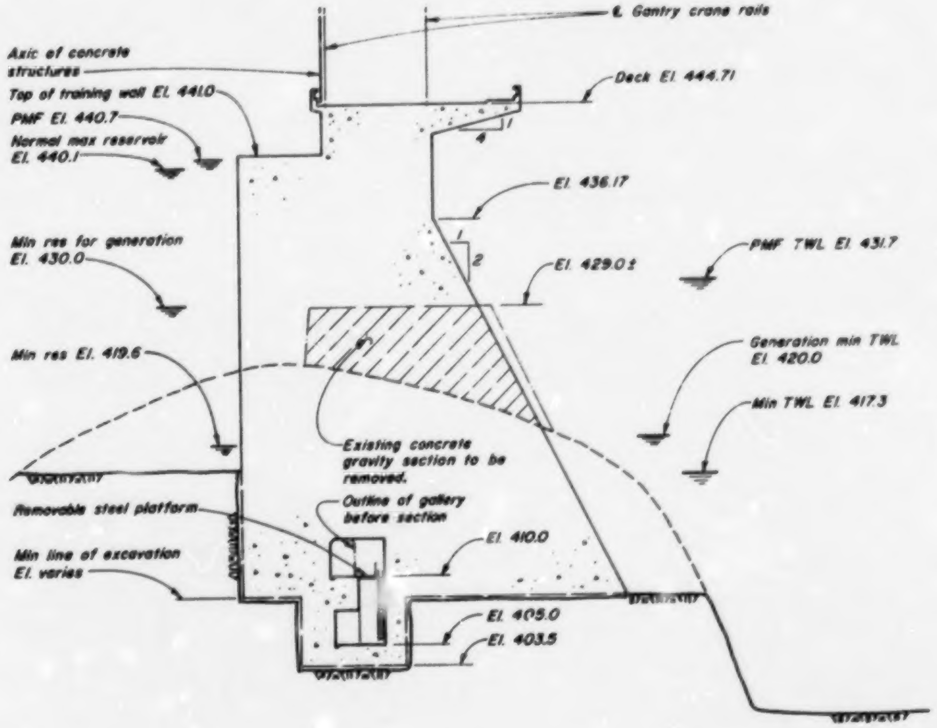
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
POWERHOUSE
DRAFT TUBES AND
DRAINAGE GALLERIES-PLAN EL. 405.0

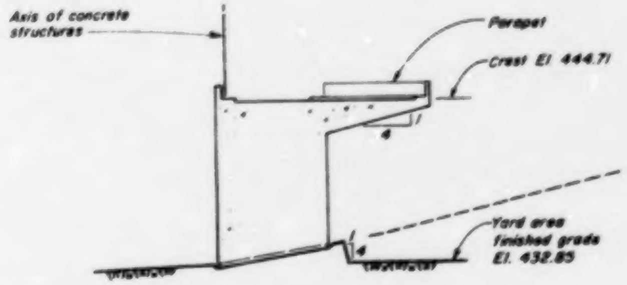
DATE MAY 1983
FIG. 8-18 R
DWN SM
DWG No. 240-C14-D315

REPORT No. H1613


Axis of concrete structures
Constr jt
Gravity junction section
Contr jt
30.0 typ
24.5 Service bay
Contr jt
Bulkhead gate storage
Access gallery El. 440.5
Access gallery El. 440.5
Hydraulic equipment room
Contr jt, typ
Gravity section
Emergency exit
Ladder
Existing north bulkhead section
El. 433.0
El. 433.0


℄ Gantry crane rails
Axic of concrete structures
Deck El. 444.71
Top of training wall El. 441.0
PMF El. 440.7
Normal max reservoir El. 440.1
4
1
El. 436.17
1
2
El. 429.0±
PMF TWL El. 431.7
Min res for generation El. 430.0
Min res El. 419.6
Generation min TWL El. 420.0
Min TWL El. 417.3
Existing concrete gravity section to be removed.
Outline of gallery before section
Removable steel platform
Min line of excavation El. varies
El. 410.0
El. 405.0
El. 403.5

SECTION $\frac{B}{8\text{-}13}$


Axis of concrete structures
Parapet
Crest El. 444.71
4
1
Yard area finished grade El. 432.85

SECTION $\frac{C}{8\text{-}13}$

Scale: 0 5 10 15 20 25 Metres

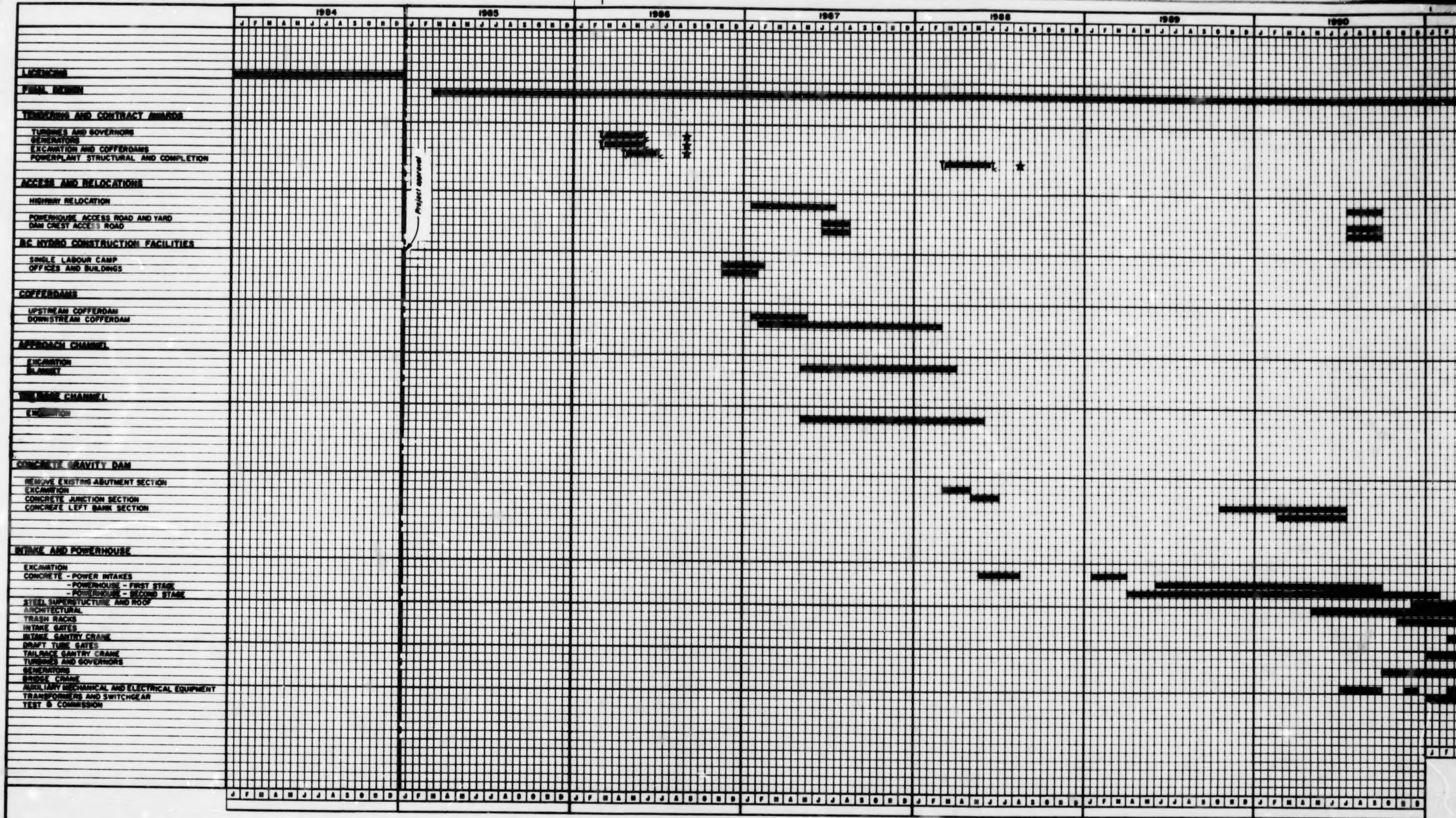
All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT
POWERHOUSE
INTAKE PLAN EL. 440.5 AND
GRAVITY SECTIONS

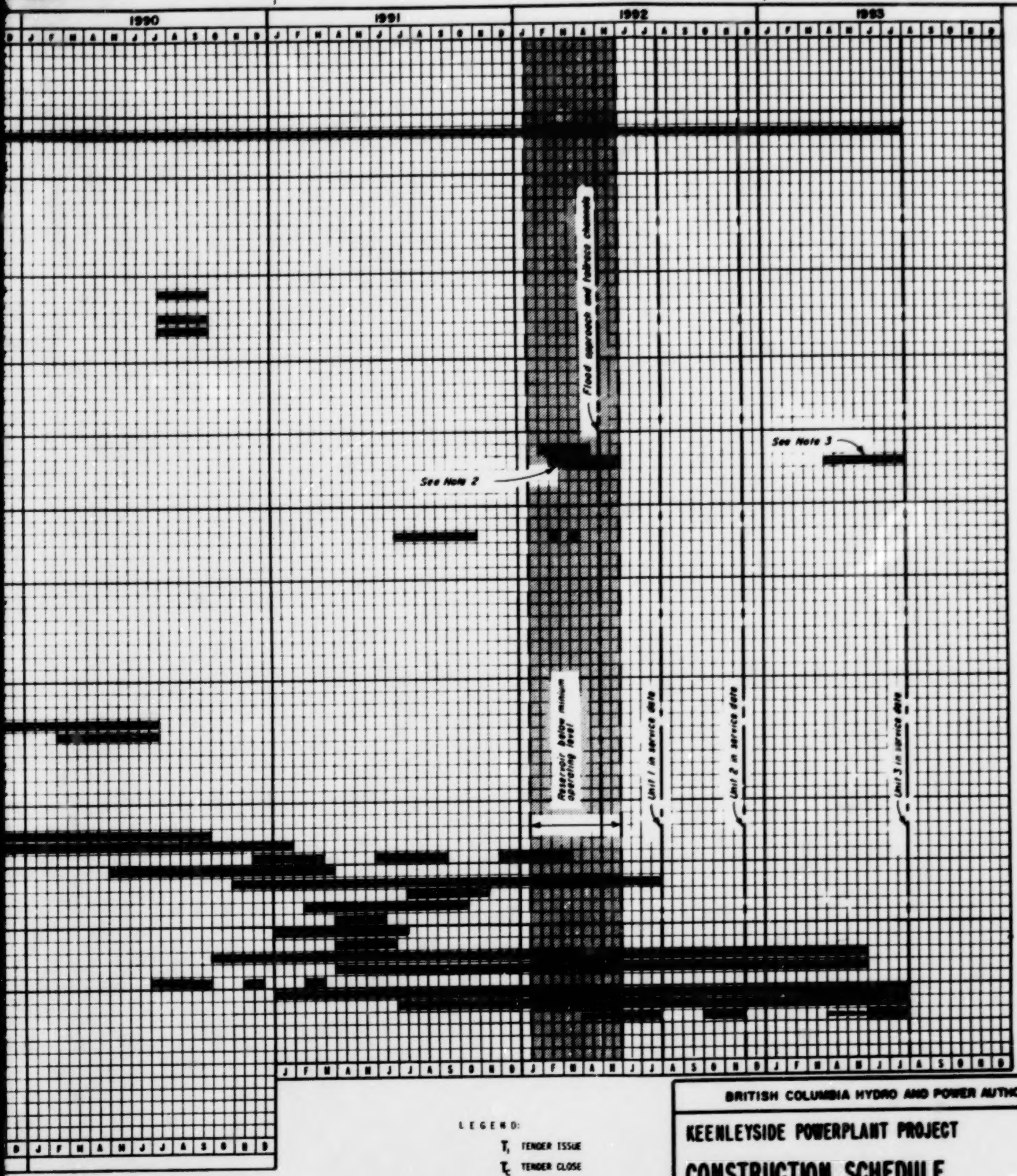
DATE MAY 1983	FIG. 8-19	R
DWN SM	DWG No. 240-C14-D316	

REPORT No. H1613



NOTES:

1. PROJECT APPROVAL IS REQUIRED BY 1 JAN 1985.
2. A WEIR, EXCAVATED IN THE DOWNSTREAM COFFERDAM, WILL
TO MAINTAIN TAILWATER LEVELS UNTIL MURPHY CREEK RES
3. AFTER IMPOUNDING OF MURPHY CREEK RESERVOIR, THE WE
EXCAVATED TO INCREASE TAILRACE TO FULL DEPTH.



LEGEND:

T_I	TENDER ISSUE
T_C	TENDER CLOSE
★	CONTRACT AWARD
▬▬▬	WET TESTING DEFERRED - (LOW RESERVOIR LEVELS)

NOTES:

1. PROJECT APPROVAL IS REQUIRED BY 1 JAN 1985.
2. A WEIR, EXCAVATED IN THE DOWNSTREAM COFFERDAM, WILL BE REQUIRED TO MAINTAIN TAILWATER LEVELS UNTIL MURPHY CREEK RESERVOIR IS IMPOUNDED.
3. AFTER IMPOUNDING OF MURPHY CREEK RESERVOIR, THE WEIR WILL BE EXCAVATED TO INCREASE TAILRACE TO FULL DEPTH.

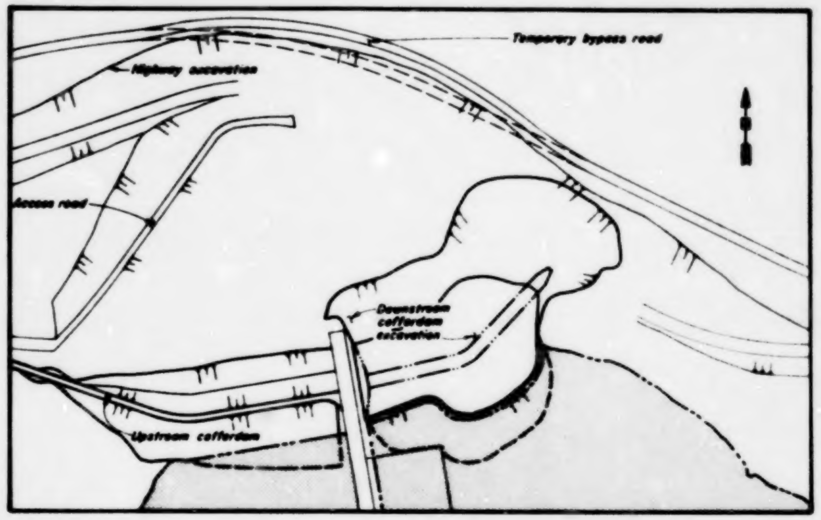
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

CONSTRUCTION SCHEDULE

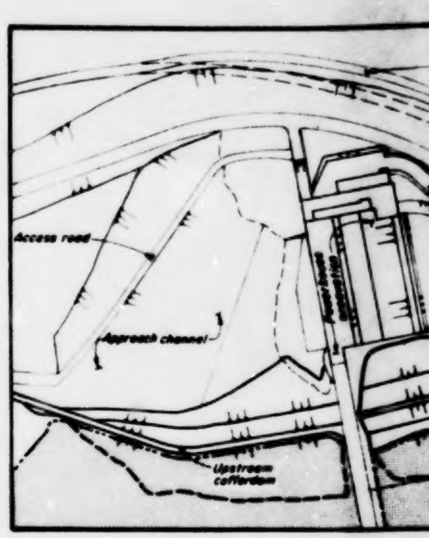
DATE MAY 1983
FIG. 9-1 R
DWN R.K.W
DWG No. 240-C14-X317

REPORT No. H1613


Temporary bypass road
Highway excavation
Access road
Downstream cofferdam excavation
Upstream cofferdam

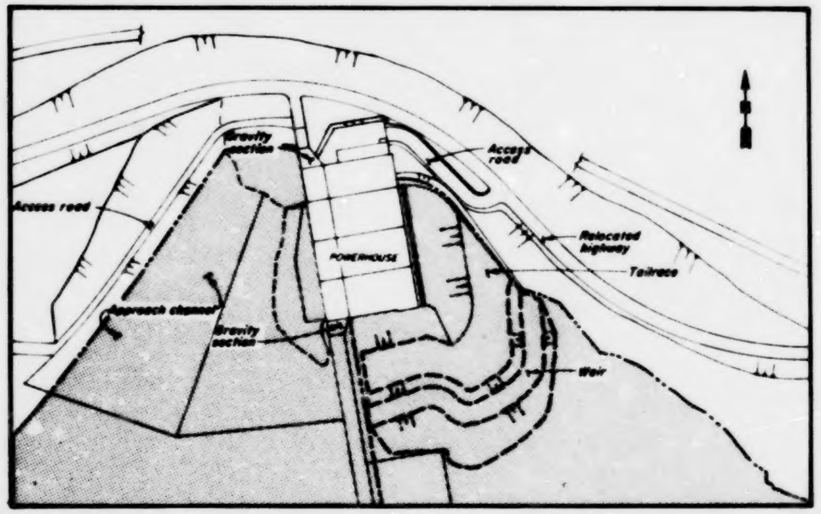
PHASE A

- CONSTRUCT CAMP
- CONSTRUCT TEMPORARY BYPASS ROAD
- CONSTRUCT UPSTREAM COFFERDAM (DURING LOW RESERVOIR LEVELS)
- START MAIN EXCAVATION AND HIGHWAY RELOCATION
- START DOWNSTREAM COFFERDAM


Access road
Approach channel
Upstream cofferdam

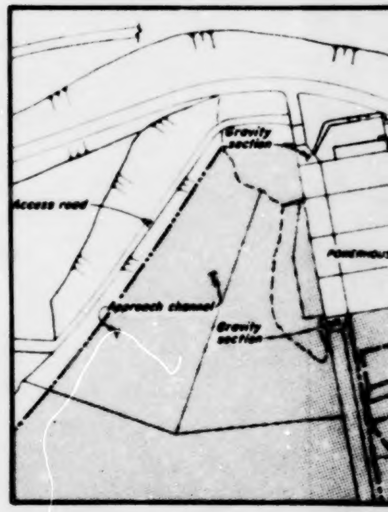
PHAS

- COMPLETE DOWNSTREAM COFFERDA
- COMPLETE EXCAVATIONS FOR HIG
GRAVITY SECTIONS, APPROACH A
ACCESS ROADS


Gravity section
Access road
Access road
Relocated highway
Tailrace
POWERHOUSE
Approach channel
Gravity section
Weir

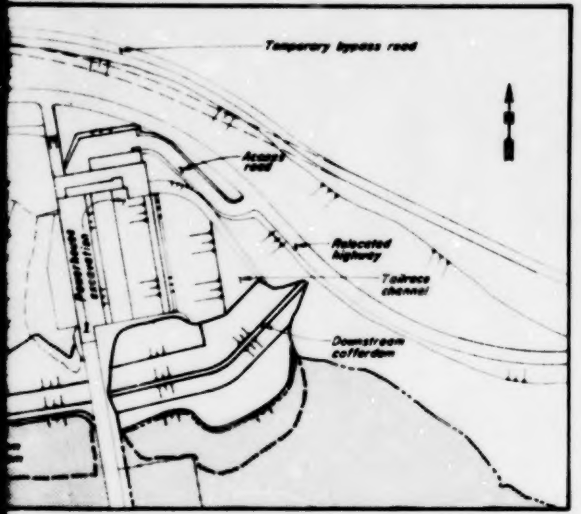
PHASE D

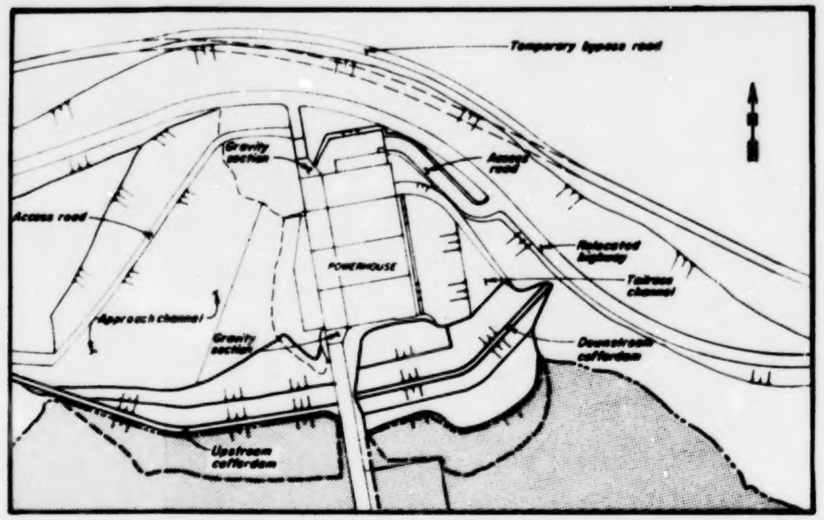
- REMOVE UPSTREAM COFFERDAM (DURING LOW RESERVOIR LEVELS)
- CONSTRUCT WEIR IN DOWNSTREAM COFFERDAM
- COMPLETE POWERHOUSE


Access road
Gravity section
POWERHOUSE
Approach channel
Gravity section

PH

- REMOVE TAILRACE WE
(AFTER MURPHY CREE


Temporary bypass road
Access road
Powerhouse excavation
Relocated highway
Tailrace channel
Downstream cofferdam

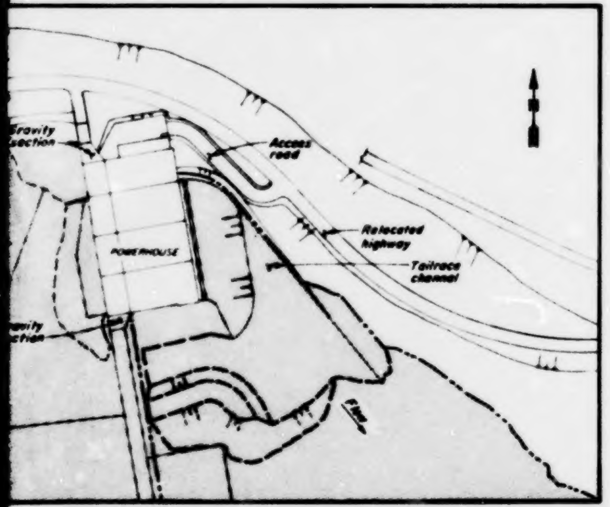

Temporary bypass road
Gravity section
Access road
Access road
POWERHOUSE
Relocated highway
Tailrace channel
Approach channel
Gravity section
Downstream cofferdam
Upstream cofferdam

PHASE B

ETE DOWNSTREAM COFFERDAM
ETE EXCAVATIONS FOR HIGHWAY RELOCATION, POWERHOUSE
TY SECTIONS, APPROACH AND TAILRACE CHANNELS AND
S ROADS

PHASE C

- CONSTRUCT POWERHOUSE AND GRAVITY SECTIONS
- INSTALL GATES AND CRANES
- START TURBINE AND GENERATOR INSTALLATION
- COMPLETE HIGHWAY RELOCATION AND ACCESS ROADS
- CONSTRUCT APPROACH CHANNEL LINING


Gravity section
Access road
POWERHOUSE
Relocated highway
Tailrace channel
Gravity section
Weir

PHASE E

- REMOVE TAILRACE WEIR TO FULL DEPTH OF TAILRACE (AFTER MURPHY CREEK RESERVOIR IMPOUNDING)

Scale: 50 0 50 100 150 200 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

CONSTRUCTION SEQUENCE

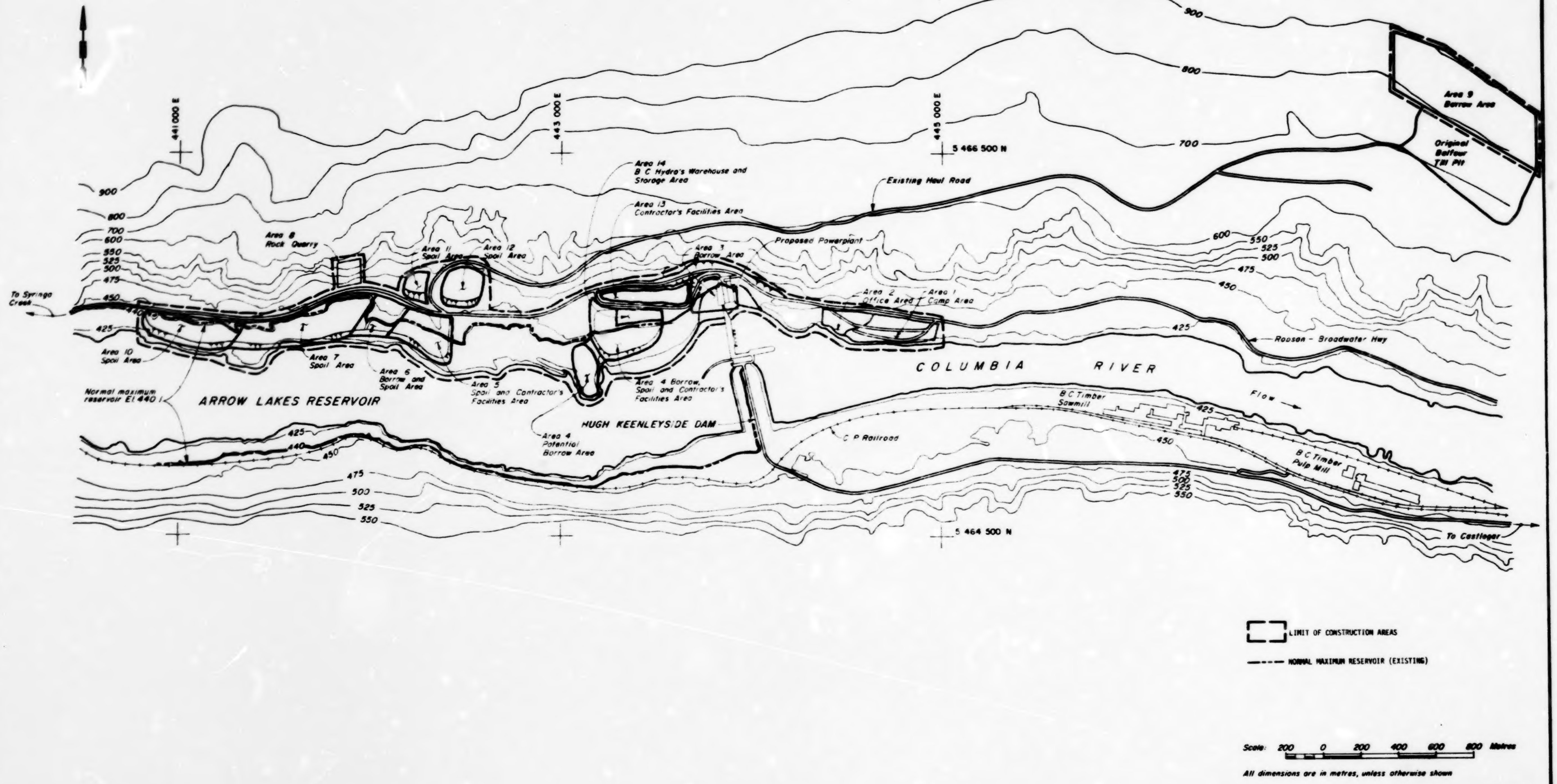
DATE MAY 1983

FIG. 9-2

R

SM

DWG No. 240-C14-D318


441 000 E
443 000 E
445 000 E
5 466 500 N
5 464 500 N
900
800
700
600
550
525
500
475
450
440
425
To Syringa Creek
Area 8
Rock Quarry
Area 11
Spoil Area
Area 12
Spoil Area
Area 14
B C Hydro's Warehouse and Storage Area
Area 13
Contractor's Facilities Area
Existing Haul Road
Area 9
Borrow Area
Original Balfour Till Pit
Proposed Powerplant
Area 3
Borrow Area
Area 2
Office Area
Area 1
Camp Area
Area 10
Spoil Area
Area 7
Spoil Area
Area 6
Borrow and Spoil Area
Area 5
Spoil and Contractor's Facilities Area
Area 4 Borrow,
Spoil and Contractor's Facilities Area
Normal maximum reservoir El. 440.1
ARROW LAKES RESERVOIR
HUGH KEENLEYSIDE DAM
Area 4
Potential Borrow Area
COLUMBIA RIVER
Robson - Broadwater Hwy
Flow
B C Timber Sawmill
C P Railroad
B C Timber Pulp Mill
To Castlegar
LIMIT OF CONSTRUCTION AREAS
NORMAL MAXIMUM RESERVOIR (EXISTING)
Scale: 200 0 200 400 600 800 Metres
All dimensions are in metres, unless otherwise shown

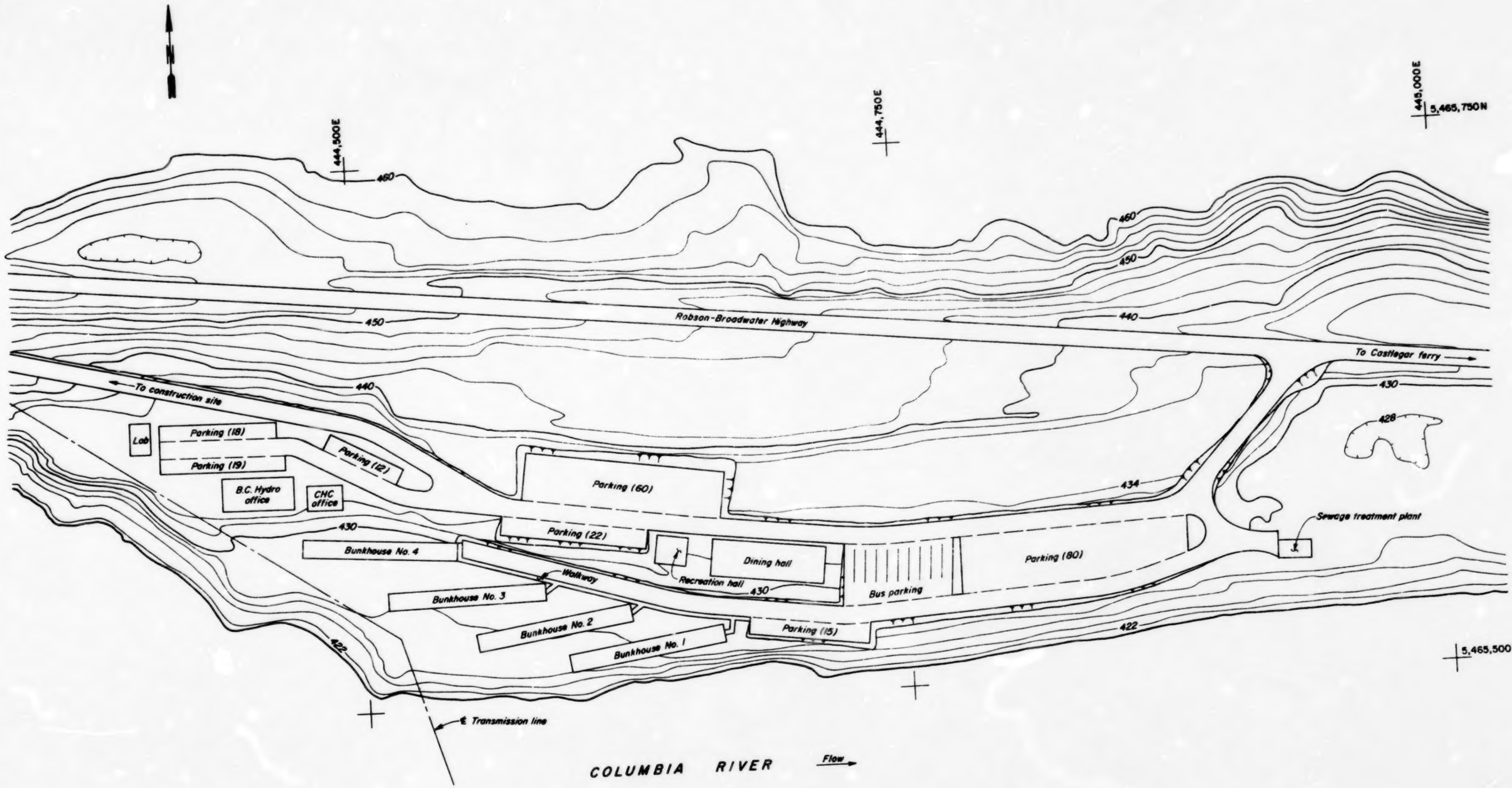
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

POTENTIAL AREAS FOR CONSTRUCTION FACILITIES

DATE MAY 1983	FIG. 9-3 R
DWN SM	DWG No. 240-C14-D319

REPORT No. H1613


N
444,500E
444,750E
445,000E
5,465,750N
5,465,500N
460
450
440
430
434
428
422
Robson-Broadwater Highway
To Castlegar ferry
To construction site
Lab
Parking (18)
Parking (19)
Parking (12)
B.C. Hydro office
CMC office
Parking (60)
Parking (22)
Bunkhouse No. 4
Bunkhouse No. 3
Bunkhouse No. 2
Bunkhouse No. 1
Walkway
Recreation hall
Dining hall
Bus parking
Parking (80)
Parking (15)
Sewage treatment plant
℄ Transmission line
COLUMBIA RIVER
Flow

Scale: 20 0 20 40 60 80 Metres

All dimensions are in metres, unless otherwise shown

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

CONSTRUCTION CAMP & OFFICES
GENERAL ARRANGEMENT

DATE MAY 1983

FIG. 9-4 R

DWN A.V.

DWG No. 240-C14-D320

APPENDICES

APPENDIX A
KEENLEYSIDE POWERPLANT PROJECT
PRELIMINARY DESIGN GUIDELINES

A.1 BASIC PROJECT DATA (for three 70 MW units with Kaplan turbines)

(a) Discharges

Flow per Unit (maximum)	500 m^3/s
Diversion Design Flood	4 290 m^3/s
Probable Maximum Flood (PMF)	10 300 m^3/s

(b) Water Levels

(i) Headwater

Minimum Reservoir	El. 419.6
Minimum Reservoir for Generation	El. 430.0
Normal Maximum Reservoir	El. 440.1
PMF and Surcharge Level	El. 440.7
Diversion Design Flood	El. 440.7

(ii) Tailwater

Minimum (no generation)	El. 417.3
Normal	El. 424.0
PMF	El. 431.7
Diversion Design Flood	El. 425.5

A.2 LOADS

(a) Mass of Materials

Granular fill	2 160 kg/m³
Concrete	2 400 kg/m³
Foundation rock	2 640 kg/m³

(b) Hydrostatic and Hydrodynamic Pressure

As applicable. (Hydrodynamic pressure acts above level of rock.)

(c) Uplift

The uplift pressures are based on the following assumptions:

1. Uplift and internal hydraulic pressures are not affected by earthquake forces and are applied over 100 percent of the base area.

2. Uplift does not develop in a crack formed during an earthquake.

3. With drains operational: full headwater pressure acting at the upstream edge of base, then varying linearly to a pressure at the drains equal to tailwater plus one-third of the headwater-tailwater difference, and then varying linearly to tailwater pressure at the downstream edge of base (for gravity structures excluding powerhouse).

4. With drains non-operational: full headwater pressure acting at the upstream edge and varying linearly to tailwater pressure at downstream edge of base (for powerhouse).

(d) Earthquake Loads

Horizontal acceleration 0.1 g with a vertical acceleration of 0.05 g acting simultaneously.

(e) Ice Load

A force of 145 kN per lineal metre is assumed to act at 0.3 m below the reservoir surface on all water-retaining structures. For spillway piers this force is assumed to be 290 kN per lineal metre of ice contact surface and acting at 0.3 m below the reservoir surface. There is assumed to be no ice load on the spillway gates.

A.3 LOAD COMBINATIONS

Three load combinations have been considered in the stability analysis as follows:

(a) Usual Load Combination - includes gravity, hydrostatic, ice and uplift force with headwater at FSL El. 440.1 m and minimum tailwater at El. 424.0 m.

(b) Unusual Load Combination - includes gravity, hydrostatic and uplift forces based on PMF conditions with headwater at El. 440.7 and tailwater at El. 431.7 m.

(c) Extreme Load Combination - includes water levels and all the loads of the usual load combination plus the hydrodynamic and inertia loads generated by the design earthquake.

A.4 MINIMUM REQUIRED OVERTURNING, FLOATATION AND SLIDING FACTORS OF SAFETY

(a) Concrete/Rock Interface and Foundation Rock

	Allowable Concrete Stresses		Minimum Factors of Safety-Sliding	
	Tensile	Compression[*1] (kPa)	Floatation[*2]	(Friction-Only Analysis)[*3]
Usual Load	0	9 000	1.2	1.5
Unusual Load	0	13 500	1.2	1.3
Extreme Load	Crack allowed tension zone neglected	27 000	1.1	>1.0

Notes:

[*1] Concrete 1 year compressive strength of 27 000 kPa.

[*2] Floatation factor of safety during construction = 1.1.

[*3] Foundation rock, coefficient of friction:

1.2 (50°) at concrete/rock interface or
1.0 (45°) for potential sliding planes in the foundation.

(b) Concrete Structures

1. Allowable compression stress: (Same as A.4(a) above)

2. Allowable tension stress (with uplift):

Usual loading	0
Unusual loading	700 kPa
Extreme loading	1 400 kPa (crack allowed; tension zone neglected)

3. Sliding stability:

$\phi = 1.0$ (45°) and

C = 0.125 x concrete compressive strength along horizontal construction joints.

Minimum acceptable shear friction factors:

Usual loading	3
Unusual loading	2
Extreme loading	1

POOR

QUALITY

ORIGINAL